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The Sun and the Planets; comparative Dimensions.

THE SUN.

BY

AMÉDÉE GUILLEMIN.

FROM THE FRENCH BY T. L. PHIPSON, PH.D.

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THE SUN.

INTRODUCTION.

The Sun is the life of the Earth.

It is the common origin, the inexhaustible source, whence have been derived for millions of centuries past all terrestrial powers, all mechanical and physical energy, as well as the powers of all living creatures, both vegetables and animals. It is the Sun that constitutes our globe a region of light, heat, and movement—in a word, a region of life, instead of a dark, dreary, and silent desert.

The heart shrinks and imagination is horror-struck by the thought that this torch of the world might some day be extinguished, and cease to bathe our Earth and the other globes submitted to its influence in its vivifying effluvia. The probability of such an occurrence is, doubtless, very slight, but we shall see that the annals of the heavens afford some similar cases. However that may be, it is, perhaps, interesting to

point out the consequences of such a catastrophe, in order to better understand the beneficial influence which the central orb of our system exerts on our world.

Primitive nations, with ignorant simplicity, looked upon the Sun as a great god of Nature. The worship of fire and of light is at the basis of all theogony. This instinctive adoration is met with again, not only among tribes far removed from the contact of civilisation, but in the midst of our own rural population, as may be seen in the following anecdote related by Arago in his account of the total eclipse of the Sun which occurred in July 1842: –

'A poor boy from the village of Sieyès, Basses Alpes, tended his flock. Completely ignorant of what was about to happen, he was alarmed to see the disc of the Sun becoming gradually obscured, for no cloud or vapoury mist was there to furnish an explanation of the phenomenon. When the light suddenly disappeared entirely, the child, in a paroxysm of terror, began to cry and to call for help. His tears still flowed when the Sun again gave forth a ray of light. Tranquilised by this sight, the lad crossed his hands and exclaimed, *O beou Souleou!* (Oh, beautiful Sun!)'

Was not this exclamation a distant echo of ancient idolatry? At the present day all traces of a superstition of this kind among the masses of the people have, doubtless, disappeared; but ignorance has re-

mained, and indifference has succeeded to enthusiasm. The farmer ploughs and manures his fields: he then confides the seed to the soil, and counts upon the rain and the sunshine to bring about a fine harvest. Does he endeavour to account to himself how the rays of the Sun operate when they thus work for him? Has he ever asked himself what this powerful assistance is, without which his labours would be vain and his soil sterile—or how it happens that night and day succeed to each other with durations which are periodically unequal—the why and the wherefore of Summer and Winter, Spring and Autumn—what are the causes of those phenomena in which he is so directly interested, namely, the winds and the rain, fine weather and storms? The manufacturer who feeds his engine with coal to transform water into steam, and thus generates force which he distributes to his various workshops, scarcely dreams, either, of the original source of all this power.

It is to the Sun, as we have said, and as we will show, that we must attribute all the marvels with which the work of Nature and the activity of man have enriched the Earth. At the present day, Science, untrammelled by the primitive ignorance and superstition that formerly veiled it with obscure symbols, is in a position to demonstrate the truth of this bold assertion.

This is why we thought of writing the present little

work, addressed to every one except astronomers and philosophers, who have in their hands all the documents which we have consulted, and who, moreover, know more than we do on this subject.

We invited our readers, a short time ago, to make a little journey with us of some three hundred thousand miles—a mere trifle—and to explore the Moon, our faithful satellite. This time the road will be longer, but we wish to pay our respects to that powerful orb whence the Earth and all the other planets are probably derived; and with filial duty, as much as by curiosity, we may safely decide on making our imagination stride over some ninety millions of miles. A railway train would require three centuries and a half to perform the journey, but we shall want only a few hours, and shall return from our excursion, I hope, with a considerable number of curious facts. We will measure the Sun, its circumference, its volume; we will weigh it in an astronomical balance, and with the help of the natural philosophers, we will estimate the intensity of its heat and its light. Finally, after having witnessed its rotation on its axis, and fixed the duration of this motion, we will explore all the points of its immense surface, of that vast ocean of fire; we will study its storms and furious tempests, which, from far off, show themselves in the telescope as spots, more or less dark, and resemble gigantic pits into which our poor little globe would drop like a pebble down a well.

After having thus closely explored the immense luminous sphere, whose power compels more than one hundred planets and innumerable comets to circulate around it in regular periods, we will retire from it, mentally, until it appears no more than a point, lost among the world of stars. We will then seek its place in the great Nebula of the Milky Way, and we shall see that it moves along in space, carrying with it its entire company of planets, towards a point situated in the direction of the constellation of Hercules, satellite, in its turn, of some other unknown sun or of a group of suns.

Such is the condensed programme of the astronomical peregrination to which we invite the reader who is curious about things in the heavens, and who may, perhaps, have asked himself the slightly embarrassing question, 'What is the Sun?'

CHAPTER I.

THE SUN AS THE SOURCE OF LIGHT, OF HEAT, AND OF CHEMICAL ACTION.

§ I. THE LIGHT OF THE SUN.

Some Notions of Photometry; what is meant by the illuminating Power and the intrinsic Brilliancy of a source of Light.—To how many Wax Candles is the lighting Effect of the Sun equivalent?—The Light of the Sun compared to the Electric Light.—Estimation of the intrinsic Intensity of the Sun's Light.

TO say that the Sun is the most brilliant source of light known is, probably, not teaching much to any one. It would be more interesting and more profitable, but much less easy, as we shall see presently, to estimate with a certain degree of precision the intensity of this prodigious focus of light. For the last two centuries several attempts have been made to measure the intensity of solar light; and although the results do not all coincide, they will be sufficient to give some idea of the luminous power of the mighty orb as compared with that of other natural or artificial sources

of light which we can observe or procure on the surface of the Earth.

Before entering into the details of this delicate question called photometry, let us lay down certain principles which are necessary to dissipate whatever may seem obscure to the eyes of readers unacquainted with optical theories.

When we speak of the intensity of a source of light, this intensity may be considered from two distinct points of view: by it we mean either the *illuminating power* of this source as compared with some other source of light taken as unity, or we mean its *intrinsic brilliancy*. Let us show by a few examples what is the difference of these two denominations.

Suppose, for instance, that we have found the illuminating power of a gas-jet of certain dimensions equal to that of sixteen candles: in this case we suppose that the gas-jet and the sixteen candles are placed at the same distance from the surface of a body which is then equally lighted up by the two sources of light. The same ratio would exist, however, between the illuminating powers of the gas-jet and of one candle taken as unity, if the distance of the gas-jet from the object lighted up was four times greater than that of the candle. This is a consequence of the law in virtue of which the illuminating power of a source of light diminishes in inverse ratio to the square of the distance, that is, becomes 4, 9, 16 . . . . times weaker,

when the distance, on the contrary, becomes 2, 3, 4 . . . . times greater.

Taken in this sense, the intensity of solar light, or the illuminating power of the Sun will be measured by the number of candles, of gas-jets, of lunar discs, of stellar lights, &c., which it would be necessary to accumulate, or to suppose collected, either at certain fixed distances from some surface, or in the sky at the distance of the stars themselves, to produce an equal degree of illumination on the surface in question.

One word now upon what is meant by the *intrinsic intensity of a source of light. Imagine that we could cut out upon the disc of the Sun a space equal to that of the flame of a candle seen at the distance of one* metre (3·28 feet English), and that we asked ourselves how many times more luminous the first surface would be than the second? The answer to that question would give the intrinsic intensity of solar light compared to that of one candle. Thus, the estimation of the intrinsic brilliancy of a source of light consists in comparing the brilliancy of a portion of the luminous surface, with that of an equal surface of another source taken as unity.

The distinction between the illuminating power and the intrinsic intensity once well understood, will furnish an explanation of the facts which we are about to relate.

Several philosophers of the sixteenth and seven-

teenth centuries, Maurolicus, Auzout, Huygens, endeavoured to measure the intensity of solar light; but it is to Bouguer that we owe the first figures having some degree of precision which bear on this delicate point of photometry. He used a concave lens to make the solar rays diverge, and so to weaken these rays to an extent which could be easily calculated; he then compared the light thus diminished with that of a candle placed at a given distance from a screen. Thus it was, in September 1725, Bouguer found that the Sun, when 31° above the horizon, and with a clear sky, lighted up the screen as 11,664 candles would have done at a distance of 0·43 of a metre, that is, like 62,177 candles at the distance of one metre ($3\frac{1}{4}$ feet English). From the law which establishes that the intensity is in inverse ratio to the square of the distances, and taking into account the loss by atmospheric absorption, we arrive at this result, viz., that the Sun at the zenith and with a clear sky illuminates an object 75,200 times more than a candle placed at the distance of $3\frac{1}{4}$ feet from this object.

In May and June 1799, Dr. Wollaston, by allowing a very thin ray of light to pass through an aperture in a camera oscura, arrived at a result which differs very little from that obtained by Bouguer. On an average he found that 5563 candles,* placed at the distance of

* Average of twelve experiments of which the two extreme results were 7770 and 3965 candles.

one foot, or 59,882 candles at 3·28 feet, illuminated an object as much as the Sun. Supposing the Sun at the zenith and the candles at 3·28 feet, the illuminating power of the former would be represented by 68,000 candles. This figure is rather smaller than that of Bouguer. But neither of the methods employed are capable of furnishing very precise results, and the atmospheric conditions were doubtless not the same in both cases.

A Carcel lamp which burns 42 grammes* ($1\frac{1}{2}$ oz. English) of pure oil per hour, gives as much light as eight or nine stearic candles; a fish-tailed gas-jet as much as seven or eight candles. We can, by means of these numbers and the results obtained by Bouguer and Wollaston, calculate easily how much the Sun's light surpasses that of either of these sources just named; but now-a-days we are able to produce artificial light, the intensity of which approaches much nearer to that of sunlight. For instance, in directing on to a piece of lime the flame of a jet of mixed hydrogen and oxygen gas, a very intense light is produced—it is that known as the *Drummond light*, the *oxy-hydrogen light* or the *lime-light*. M. Edmond Becquerel, by

* [The gramme is 15·438 grains Troy. The use of the French weights and measures of capacity has become very generally adopted in England in works on science, on account of their simplicity and the advantages of the decimal system over our old system.—P.]

using an apparatus that consumed $3\frac{1}{2}$ litres (about $6\frac{1}{4}$ pints) of gas per minute, estimated the quantity of light produced as equal to 160 or 180 candles. A magnesium wire only one-hundredth of an inch in thickness gives, on burning in the air, the light of 74 candles, or of 110 candles if it is burnt in oxygen gas; in the latter case its intrinsic brilliancy is equal to 500 times that of the candles. Lastly, the electric light obtained with a nitric acid battery, having from 50 to 100 couples, gives a quantity of light which M. Becquerel considers equal to from 400 to 1000 candles. In the latter case, the light of the Sun at the zenith, according to Wollaston's and Bouguer's results, would have an illuminating power surpassing only 75 times that of the electric light at $3\frac{1}{4}$ feet distance.

With more powerful batteries a light is obtained which approaches still nearer to the luminous intensity of the Sun. Thus, MM. Fizeau and Foucault, on comparing the brilliancy of an electric light produced by three series of Bunsen's elements, each series being composed of 46 couples, with the light furnished by the Sun on a clear day in the month of April, found that the illuminating power of the solar rays was not equal to much more than two and a half times that of the electric light.

In all these determinations we are dealing only with the illuminating power of the Sun. Arago has

estimated the intrinsic intensity of its light in the following manner. He began by comparing with it the light of the atmosphere in the neighbourhood of the Sun, and he found that all around the disc, at an angular distance from it about equal to its diameter, the atmospheric light was 511 times less intense than the light of the Sun itself. Such being the case, when the flame of a candle is projected, not only on to the disc of the Sun, but also on that portion of the heavens which surrounds it within the limits mentioned, the flame disappears entirely to the eye of the observer, nothing is seen but the carbonised wick, the outline of which detaches itself in black upon the light background. Now, Bouguer has shown that a light which causes another light to disappear in this way must be at least 64 times more intense than the latter. The widespread atmosphere which surrounds the Sun possesses therefore an intrinsic intensity of light equal to at least 64 times that of the candle-flame: so that the intensity of the solar light itself is 511 × 64, or 32,704 times stronger than the light of a candle. We speak now of its intrinsic brilliancy and not of its illuminating power.

But this method of valuing the Sun's light, indicated by Arago in his 'Astronomie Populaire,'* only gives an inferior result. According to M. E. Becquerel,

* He states 15,000 instead of 32,704, which appears to be a typographical error.

the flame of a candle has a visible surface of about 0·27 square inch; a circle of this size would have to be placed at a distance of about $6\frac{3}{4}$ feet, in order that its diameter may subtend an arc of 30′, that is, in order to have the same apparent dimensions as the Sun. It results from this, that if we take for unity the intrinsic brilliancy of the light of a candle, that of solar light becomes, according to Bouguer, 186,400, and according to Wollaston, 179,130.

Absorption of Sunlight by the Atmosphere; it varies according to the height of the Sun above the Horizon.—Variation of Light according to the Seasons.

In all the preceding comparisons we have spoken only of the solar light, such as it reaches the ground after having passed through the layers of gaseous matter which constitute our atmosphere. These layers are more or less pure, more or less charged with watery vapour and solid particles suspended in the air, dust, and germs of all descriptions. A certain fraction of the sunlight is absorbed during its passage through this medium of variable composition, and this absorption is greater the nearer the Sun is to the horizon.

Bouguer, who has studied this subject, estimates that this atmospheric absorption reduces the intensity of the light of the Sun to the following figures, sup-

posing 10,000 to represent the intensity if there were no atmosphere to the Earth:—

At the zenith			..	8,123
At 50° above the horizon			..	7,624
30	"	"	..	6,613
20	"	"	..	5,474
10	"	"	..	3,149
5	"	"	..	1,201
4	"	"	..	802
3	"	"	..	454
2	"	"	..	192
1	"	"	..	47
0	"	"	..	6

By inspecting this table we see that at sunrise the light is 1354 times less intense than when the Sun is at the zenith; at Paris, on the day of the Summer solstice, about the 20th of June, the Sun mounts as high as 64° at noon: on that day its light at noon is more than 1300 times as intense as at four o'clock in the morning, the hour at which its disc touches the horizon.

We speak here only of the absorption of the light of the Sun by the air, and the table calculated by Bouguer expresses the proportions in which the gaseous envelope of our Earth diminishes the force of sunlight through a clear sky. But most frequently its intensity is still more diminished by masses of vapour, fogs, and clouds in suspension in the atmosphere. The light of the Sun is thus diffused before arriving

at our eyes, which receive its impression after it has undergone reflexion at the surface of clouds and terrestrial objects.

Before sunrise and after sunset, when the luminous disc is not yet, or is no longer visible, its light illuminates directly the upper regions of the atmosphere and comes to us by direct reflexion, and also by its refraction in the gaseous medium overhead. The duration of the day, or rather of daylight, is thus augmented by the twilight and the aurora. Finally, during the night even, we may be still lighted by sunbeams, for they are reflected from the surface of the Moon and the planets, and cause these orbs to shine upon the obscure background of the starry firmament.

From winter to summer the variations of the intensity of solar light may be very great on account of the changes in the purity or absorbing faculty of the atmosphere. But, speaking astronomically, at the limits of our atmosphere, it remains the same, for a variation in the distance of a luminous source does not affect its intrinsic brilliancy. That which does change with the distance is the apparent diameter of the orb, consequently, the luminous surface and the illuminating power. When we calculate the ratio of these various elements, we find that if the lighting power of the solar disc is 1·000 at the mean distance of the Sun, that is, on the first of April and first of

October, at its greatest distance from the Earth, or aphelion, on the first of July, this power is reduced to 0·966, and in January, period of the perihelion, or at the Sun's minimum distance from the Earth, the illuminating power becomes 1·033. But for these numbers to correspond to real variations in the intensity of daylight, we must suppose the Sun to be in each case at the same height above the horizon, and seen in identical atmospheric conditions, which is very difficult to realise in such widely different seasons.

The light of the Sun compared to that of the Stars and of the Moon—Difference of intensity between the light of the borders and that of the centre of the solar disc.

The philosophers whose photometric experiments we alluded to above have also endeavoured to compare the light of the Sun with that of other cosmical sources of luminosity, such as the Moon and the Stars.

Huygens estimated the light of the Sun to be at least equal to 765 million times that of Sirius (the Dog Star). According to Wollaston it is much greater than this even, he calculates it to be equal to twenty thousand millions of times the light of the said star, which is nevertheless, as every one knows, the most brilliant star in our sky. It results from this that to

see the Sun reduced in splendour till its brilliancy would equal only that of Sirius, our planet must travel through space to a distance 140,000 times that which now separates us from the central orb of our system. On the other hand, if Sirius approached us and took the place occupied by the Sun, its light would be equivalent to that of ninety-four suns similar to our own!

Bouguer, on comparing the light of the Sun to that of the full Moon, drew, from a considerable number of observations, the conclusion that the illuminating power of the Sun is equal to 300,000 times that of the disc of our satellite. Curious to relate, Wollaston, who agrees tolerably with Bouguer as to the comparative intensities of the sunlight and a candle's light, found that the illuminating power of the Sun is to that of the Moon as 801,072 is to 1. The difference between these two results is so enormous that we are unable to explain it: it is an experiment which should be made over again.

However that may be, taking as unity the intensity of solar radiation, and putting aside atmospheric absorption, we can calculate what the intensity of this radiation is on the surface of each of the planets. Intrinsically considered it remains the same; but on account of the variation in the apparent diameter of the Sun, and consequently of the radiating surface of the disc, the quantity of light and heat which reaches

each planet will be found to vary in inverse ratio to the squares of their distances from the common focus. From Mercury, the planet nearest to the Sun, to Neptune, the most distant, the light of the Sun diminishes in the proportion of 7000 to 1, or thereabouts.

To conclude what we have to say of the Sun considered as a source of light, we have still to speak of the difference of intensity which exists between the various regions of its surface.

It appears certain, as Bouguer was the first to observe, that the surface of the Sun's disc is not uniformly luminous; the centre possesses a more intense light than the borders. According to this author the ratio of these intensities is as 48 is to 35. Nevertheless, Arago, on comparing by means of his polariscope the light of the edges of the Sun with that of the centre of the disc, could not detect a difference of $\frac{1}{40}$th between their respective intensities. More recently Professor Secchi has made a great number of comparative measurements by means of a photometer supplied with a revolving wheel, and he concludes that the light of the centre is as much more intense than that of the borders as 4 or 3 is to 1; and even in this case the light was taken at fifty seconds from the edge; on the edge of the disc itself he estimates the difference to be scarcely $\frac{1}{20}$th. Whence arise such divergences of results obtained by observers

equally clever and learned? Really we cannot tell. Sir John Herschel, in the sixth edition of his 'Outlines of Astronomy,' positively asserts, that when the entire disc of the Sun is seen through a telescope of moderate power, armed with a dark glass in order that we may examine it easily, it becomes evident that the borders of the disc are much less luminous than the centre. We can assure ourselves that this is not an illusion, by projecting the image of the Sun moderately magnified and not darkened, so that it shall form a circle about four inches in diameter upon a sheet of white paper. A photographic proof of the Sun, taken on the 7th August, 1863, which we have now before us, shows a very marked difference between the intensity of the light at the edges and at the centre. But this may be due more especially to a difference in the chemical activity of the rays. We shall see presently of what importance are the facts we are now discussing with regard to the physical constitution of the Sun.

§ 2. The Heat of the Sun.

The temperature of our globe is due to three sources of heat: that of interplanetary space, internal heat, and solar heat.

Three principal sources of heat combine to impart to our earth the temperature which it possesses;

these are, in the first place, the internal or proper heat of the mass of the globe itself; in the next, the heat communicated to us by interplanetary space through the various regions of which the earth passes successively; lastly, the heat which we receive from the Sun.

A given point of celestial space is incessantly traversed by rays of heat emanating from the most distant orbs, stars, suns, dark bodies which rotate around them—in a word, from every particle of matter conglomerated or disseminated in the heavens. This continual radiation gives rise to a certain degree of temperature, which may vary, however, from one point of the universe to another, but will remain almost the same in the interior of our planetary world, the dimensions of this world being extremely small in comparison to the distances of the radiating sources.*

Fourier was the first to recognise the existence and to estimate the extent of this fundamental heat of space. He has shown that if the globe, besides its internal heat, of which we shall say two words

* This signifies that the temperature of that portion of space circumscribed by the orbit of Neptune, the most distant planet from the Sun, is uniform or constantly the same, if we put aside the heat radiated by the Sun and the other planets. But as the Sun and the whole planetary system are travelling through space in a certain direction, this motion may lead the Earth and its companions through regions of space having

presently, only received heat from the Sun,—that is, if interplanetary space was entirely devoid of heat—the loss of heat during the night and during the winter season would be so great, that no living being could resist the abrupt variations which would inevitably occur in the temperature of any given locality. The temperature of space is nevertheless very much lower than that of the coldest polar regions: Fourier stated it to be 60° below zero centigrade, and according to Pouillet it is even lower than this; he estimates that it cannot be greater than − 142°. However low it may be, the temperature of celestial space is a physical cause ever in operation, which moderates temperatures at the surface of the globe, and gives to our planet a fundamental heat, independent of that derived from the Sun, and of that which the interior mass of the globe has preserved.

The increase of temperature which is observed to occur in the crust of the earth as we descend towards the centre, furnishes an incontestable proof of the existence of a proper heat belonging to the mass of the globe itself. Fourier has proved that the action

temperatures which are not all alike, and may vary in a given number of years or of centuries.—[Some philosophers imagine that our planetary system has for the last few years been traversing a comparatively warm region of space, causing us to experience very hot summers and mild winters and other meteorological phenomena.—P.]

of the solar rays alone is not sufficient to account for this gradual increase of temperature, for, admitting that this action has continued for a lapse of centuries sufficient to bring the heating to its maximum, we should find, at a certain depth, an uniform temperature; and if, on the contrary, this maximum has not yet been reached, the temperature of the crust should decrease with the depth. In both these cases the results of the hypothesis would be contrary to actual observation.

The internal heat of the globe is propagated by conduction from the centre to the outer crust, and even to the surface of the soil whose temperature, according to calculation, cannot be raised by it more than $\frac{1}{36}$th of a degree centigrade: this amount would nevertheless be sufficient, in the course of a century, according to Fourier, to melt a layer of ice $3\frac{1}{4}$ yards thick.

By this radiation of internal heat the terrestrial globe is constantly becoming colder; but the loss of heat is compensated for by solar radiation, which constitutes the third and principal source of terrestrial heat, and forms the principal subject of this chapter.

Intensity of solar heat at the surface of the terrestrial globe. Its absorption by the watery vapour of the atmosphere.

To appreciate rightly what this powerful source of heat is in itself, we must endeavour to point out, among

its very variable effects observed at the surface of the earth, those which are constant. We see these effects vary from hour to hour during the day, change from day to day and from season to season. Observation teaches us also that there exists a great difference of temperature in the various regions of the globe, according to their latitude; so much so, that we can easily distinguish three kinds of zones or climates, the temperate zone, the tropical zone, and the glacial or polar zone; for solar heat is distributed to them in a very unequal manner in the course of a year.

What are the causes of these variations and these differences? The most remarkable and the most constant are the movements of the Earth. Our planet, in turning on its axis whilst it circulates round the Sun, presents alternately to the latter different portions of its surface. This double motion produces day and night, the seasons, and the year; and as the axis of the Earth always remains parallel to itself, it results that the duration of the Sun above each horizon, and its height, greater or less according to the hour of the day and the period of the year, are variable, and these variations are precisely the causes of the various temperatures which constitute the different climates. Moreover, the Earth is not always at the same distance from the Sun; solar heat has, therefore, from this circumstance alone, a variable intensity.

Finally, the Earth's atmosphere through which the rays of heat pass before they are felt by us, is more or less pure, more or less charged with vapour: it therefore absorbs a variable amount of these rays.

It is easy to see how indispensable it was to take all these facts into consideration, and to determine their value by calculation and observation, before drawing any conclusion as to the intrinsic intensity of solar heat. De Saussure and Sir John Herschel were the first to attempt this intricate problem, of which Pouillet in 1838 gave a more complete solution. The paper published by this learned philosopher had for its object the following questions, which we give literally, in order to furnish some notion of the complicated conditions of the problem:—'To determine the quantity of solar heat which falls perpendicularly, in a given time, upon a given surface; the proportion of this heat which is absorbed, during its vertical transit, by the atmosphere; the law of this absorption at various angles; the total quantity of heat which the Earth receives from the Sun in the course of a year; the total quantity of heat which is emitted every instant by the entire surface of the Sun; the elements required to ascertain whether the mass of the Sun is cooling gradually from century to century, or whether there exists a cause destined to reproduce the heat which is constantly emitted by radiation; the elements which will permit us to determine its

temperature . . . . the temperature which we should observe everywhere on the surface of the globe if the action of the Sun were not felt; the increase of temperature due to solar heat: the relative quantities of

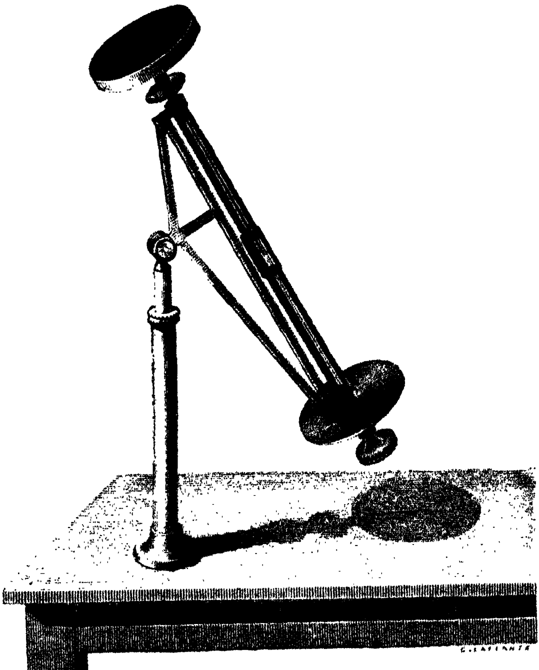


Fig. 1.—Pouillet's Pyrheliometer.

heat which the Earth receives from the Sun and from space, that is, from all the other celestial bodies.'

Fig. 1 represents one of the instruments which

Pouillet used to measure the intensity of solar heat, and to which he has given the name of pyrheliometer. We quote from our work entitled 'Les Phénomènes de la Physique,' the following concise description of it, and mode of experimenting with it:—

'At the upper part is seen a very thin cylindrical vessel of silver, the surface of which, turned towards the Sun, is covered with lamp-black. This vessel is filled with water, and the temperature of the liquid is given by a thermometer, the bulb of which penetrates into the interior of the cylinder, whilst its stem is protected by a brass tube having a longitudinal slit, which permits us to read the height of the mercury. At the other extremity of the tube, a disc having the same diameter as the cylindrical vessel, receives the shadow of the latter, and assures us that the blackened surface is exposed normally to the direction of the solar rays: that is the case when the lower disc is exactly covered by the circular shadow of the upper disc.

'We commence by taking the temperature of the instrument; its blackened surface is then exposed towards a portion of the sky without clouds, but so that it cannot receive any solar rays. In the course of five minutes the radiation of the instrument causes a certain fall of temperature. On then directing the instrument towards the Sun, the blackened disc receives, for the space of five other minutes, the solar

heat of the rays which fall perpendicularly upon the disc. The temperature is again observed on the thermometer. Finally, the instrument is allowed to radiate towards space for five more minutes in its first position, and the final cooling is noted. The first and third of these observations are necessary to determine the quantity of heat lost by the radiation of the instrument to space during the time that it is exposed to the Sun; this quantity is the mean of the two degrees of cooling observed. In adding this mean to the degree of heat produced by exposure to the direct rays of the Sun we obtain the total increase of temperature; and from this we can calculate the number of *calories** absorbed in one minute by any surface equal to that of the blackened disc.'

The rise of temperature indicated by the pyrheliometer depends first upon a constant quantity of heat, which Pouillet has named the *Solar constant*, because it expresses the constant heating power of the Sun. It depends next upon another quantity, that he called the *atmospheric constant*, which is only uniform for the day of observation, and varies from one day to another, according to the clearness of the sky, and according as the atmosphere absorbs more or less of the incident solar rays. Lastly, it depends principally upon the thickness or extent of atmosphere

* A calorie is the quantity of heat required to raise the temperature of 1 kilogramme of water 1° centigrade.

which the solar rays have to traverse: or, in other words, upon the height of the Sun above the horizon.

Fig. 2 shows plainly how much this thickness varies with the height of the Sun, not to speak of refraction which causes the rays to travel over a still longer route.

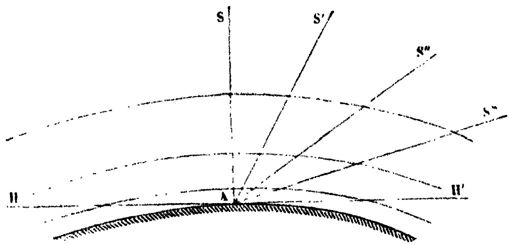


Fig. 2.—Various extents of atmosphere through which the solar rays pass, when the Sun is at various heights above the horizon.

Now, here are some of the results which M. Pouillet has deduced from a great number of observations.

If our atmosphere could transmit the whole of the solar heat without absorbing any of it, which is equivalent to exposing the instrument at the limits of the atmosphere where it would receive the whole of the heat which the Sun radiates to our globe, every square metre (1·196 square yard) of soil upon which the rays fall vertically, would receive, per minute, 17,633 calories, or heat-units.

But the absorption exerted by the atmosphere diminishes this quantity. With a perfectly pure sky

and when the rays of heat pass vertically through the air (that is, when the Sun is at the zenith), this absorption is from 18 to 25 hundredths. It increases, of course, the more oblique the rays are. If we consider the total amount of heat that falls upon the whole of the hemisphere which is lighted and warmed at the same time by the Sun (fig. 3), it is evident that the solar rays reach the surface of the Earth at every possible angle. They are vertical at A, where the Sun is at the zenith; horizontal at the points B and C, for instance, where it is at the horizon, more or less oblique at the intermediate points such as D. Thus, even if we suppose the atmosphere to be perfectly serene, nearly half the solar heat is absorbed. The portion of it which really reaches the soil is scarcely more than 5-10ths or 6-10ths of the whole.

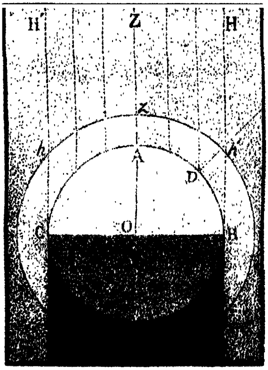


Fig. 3.—Absorption of the heat of the Sun by the atmosphere at different points of the terrestrial hemisphere.

As the Sun, according to what we have just said, transmits in one minute to every square metre (1·196 square yard) of ground that its rays strike vertically, a quantity of heat equal to 17,633 calories,

it is easy to calculate the entire quantity of heat which our globe and its atmosphere receive from the Sun in one year; it is that quantity which is received upon a surface equal in extent to one of the great circles of the Earth. We find this quantity to be about *twelve hundred quintillions of calories, expressed arithmetically by the figure 1,210,000,000,000,000,000,000.*

This quantity of heat is so great that we can form no idea of it. Pouillet used to talk of it thus:—'If the total quantity of heat which the Earth receives from the Sun in the course of one year were uniformly spread over all the surface of the globe, and if it were employed, without any loss, in the operation of melting ice, it would be capable of melting a layer of ice enveloping the whole globe and of a thickness of nearly 31 metres ($33\frac{3}{4}$ yards). This is the simplest way of expressing the total quantity of heat which the Earth receives every year from the Sun.'

The absorption of solar heat by the atmosphere evidently depends upon the thickness of the atmospheric layer which the rays pass through; but for equal heights of the Sun above the horizon (that is, for equal thicknesses of air passed through), the absorption varies in the same locality according to the season. Now it has been found that it is not the air itself (that is, the mixture of oxygen gas and nitrogen gas), which absorbs the most heat. The watery vapour or steam present in the atmosphere in

very variable proportions, has an absorbing power at least seventy times more considerable than pure dry air. This explains the fact observed by Professor Secchi, namely, that solar radiation is less intensely felt in Summer than in Winter when the Sun is at the same height: in Summer the quantity of vapour contained in the air is much greater than in Winter.

It results from some experiments made at different altitudes by the late Professor Forbes, by the German meteorologist Kaemtz, and afterwards again by M. Martins, of Montpellier, that the intensity of solar radiation is much greater on the mountains than in the valleys. The reason is, in the first place, because the layer of atmosphere which the rays pass through is less extensive; and next, because the air above the mountains is much dryer, much less charged with vapour, than the air of the plains. Nevertheless, we feel it colder the higher we ascend, so that there is an apparent contradiction here, which is not difficult to explain. The objects which receive directly the influence of the solar rays get heated, whilst the air absorbing only a small quantity of heat remains cold. 'Never,' says Professor Tyndall, 'did I suffer so much from solar heat as when descending from the *corridor* to the *grand plateau* of Mont Blanc, on the 13th August, 1857; whilst I sunk up to the waist in the snow, the Sun darted its rays upon me with intolerable fierceness. On entering into the shade of the *Dôme du Gouté*

these impressions instantly changed, for the air was as cold as ice. It was not really much colder than the air traversed by the solar rays; and I suffered, not from contact with warm air, but from the stroke of the Sun's rays, which reached me after passing through a medium as cold as ice."

Vapour of water arrests a greater proportion of solar rays than the air in which this vapour is disseminated; but these rays are composed, as we all know, of two different species of radiation,—luminous radiations and obscure radiations; and these two kinds of radiations undergo very unequal absorptions. The first pass almost entirely through the air and reach the surface of the ground; the others, on the contrary, are mostly absorbed. Therefore, though the atmosphere prevents a large portion of the solar heat from reaching the surface of the globe, it possesses the faculty of compensating for this by retaining that which warms it. Without the presence of this atmosphere and the vapour it contains, the radiation of heat from the surface of the soil towards celestial space would meet with no obstacle, and the loss of heat would be something enormous: this is, in fact, what happens to a certain extent on high mountains. Soon after sunset a rapid cooling would succeed to the intense heat of the direct rays of the Sun; in a word, we should have between the maximum and minimum temperature of the day, or the month, an

enormous difference. This is what is observed on the high plains of Thibet, and accounts for the rigour of the winters and the fall of the isothermal lines in these regions.* Professor Tyndall has remarked that 'the suppression, during one summer night, of the watery vapour contained in the atmosphere which covers England, would have for effect the destruction of all plants that are killed by frost. In the desert of Sahara, where "the soil is fire and the wind flame," the coldness of the nights is often very painful to bear. Even in that hot climate ice can be formed during the night.'

Intrinsic Intensity of the Sun's Heat.—Solar Heat would melt every day a layer of ice 17 kilometres ($10\frac{1}{2}$ miles) thick, enveloping the Sun.—Heat of Space compared with the Heat of the Sun.

But let us return to the heat of the Sun. Let us estimate its intrinsic intensity. We must first observe that the means employed by physicists to measure the

* [As rough surfaces radiate more than smooth surfaces, a forest district on the mountains is sometimes very remarkable in this respect. In my mineralogical expeditions among the woody hills of Waldeck, in Germany, I have often been surprised by the rapid cooling of the air immediately after sunset. After a hot July day, when a simple *blouse* was almost intolerable, no sooner had the Sun disappeared below the horizon, than a great-coat was found to be an exceedingly pleasant article of clothing.—P.]

intensity of the calorific radiation of the Sun at the surface of the earth only yield approximative results. The pyrheliometer of Pouillet yields a minimum result, because a portion of the heat is evidently absorbed: the figures given above as the consequences of his experiments are, therefore, rather below the truth. By adopting them provisionally we can calculate the quantity of heat which the Sun gives, not only to the Earth, but to the entire heavens; that which the solar globe, in fact, radiates all around itself, from every point, and distributes to the whole universe.

When the Sun is at its mean distance from the Earth, the quantity of heat which it distributes per minute to 1 square metre (1·196 square yard) is, as we have seen, 17,633 calories. It is evident that the same quantity is received by every square metre composing the surface of a sphere having the Sun for its centre and the distance from the Sun to the Earth, for its radius. We find for the entire sphere (that is, for the radiation which it receives from the Sun in one minute), a number of calories equal to 4,847, followed by 25 ciphers. We may as well remark that the surface of this sphere equals 2,150,000,000 times the surface limited by a great circle of the Earth. It is, therefore, by the latter figure that we must multiply that which we found above for a terrestrial hemisphere, if we wish to obtain the total quantity of

heat radiated by the Sun in the course of one year. Let us represent these terrible figures in another way, and say with Pouillet:—

'If the total quantity of heat emitted by the Sun were exclusively employed to melt a layer of ice closely surrounding the solar globe, that quantity of heat would be sufficient to melt in one minute a layer 11·8 metres (12·862 yards), and in one day a layer 17 kilometres ($10\frac{1}{2}$ miles) thick.' This same quantity of heat, according to Prof. Tyndall, 'would boil in one hour 2,900 thousand millions of cubic kilometres of water at the temperature of ice. Expressed in another way, the heat emitted by the Sun in one hour is equal to that which would be produced by the combustion of a seam of coal 27 kilometres (16·65 miles) thick.'

Sir John Herschel, again, has made the following ingenious comparison, which shows, in a very original manner, the prodigious activity of this immense focus of heat, of which the Earth absorbs at most a portion equal to 1-2,150,000,000th. 'Let us imagine,' says he, 'a cylindrical pillar of ice, 45 miles in diameter, to be continually darted into the Sun, and that the water produced by its fusion is continually carried off. In order that the heat given off constantly by radiation should be wholly expended in its liquefaction, it would be necessary to plunge the cylinder of ice into the Sun with the velocity of light, or, in other words, the heat of the Sun can, without diminishing its

intensity, melt in a second of time a pillar of 1590 square miles at its base, and 194,626 miles in height.'

It is necessary to observe that the determination of the intensity of solar heat-radiation reposes upon no hypothesis. 'It is,' as Pouillet remarks, 'independent of the real nature of the Sun, of the matter which composes it, of its radiating power, of its temperature, and of its specific heat; it is simply the immediate consequence of the best-established principles regarding radiating heat, and the figure arrived at in our experiment.' *

We intimated at the commencement of this chapter that Pouillet had determined, approximately, the temperature of interplanetary space, and found it to be about 142° below freezing point. Now, it results from the researches of the same acute observer upon the

* This figure alone will be, probably, modified when the same experiments shall have been repeated several times in localities which differ by their geographical position, their altitudes, and their climates, so that all causes of local perturbation shall have been eliminated. Moreover, we shall have to take into account the diffusive power of lamp-black, which Pouillet has neglected to do, because, when he made his experiments, observers considered the absorbing power of lampblack to be absolute. In any case, the figures which express the measurement of solar radiation, given in the text, must be rather below reality than above it. Professor Quetelet and M. Alt[illegible]s, who have repeated the experiments of Sir John Herschel and M. Pouillet, have arrived at numbers which are double and treble those we have given above.

quantity of heat which celestial space communicates to the Earth and its atmosphere, in the course of a year, that this heat would be able to melt a layer of ice 26 metres (27½ yards) thick enveloping our globe.

Thus, on the one hand, the heat of the Sun would melt a layer 31 metres (33¾ yards); and, on the other, the heat derived from space would melt another layer of 26 metres (27½ yards). The latter is, then, equal to about 5-6ths of the first; which result cannot fail to appear paradoxical. But when we reflect that the disc of the Sun seen from the Earth only occupies the 1-200,000th of the celestial vault, that the radiating surface of the central orb, compared with that of the celestial space which surrounds the Earth, is 200,000 times less, we are no longer surprised to find that a medium so cold as space can produce a calorific effect on our globe nearly equal to that which the Sun itself produces.

Solar Heat: its Mechanical Effect on the Surface of the Earth.

One of the greatest discoveries of modern science is, without doubt, that which establishes the correlation of mechanical work and heat, or the possibility of converting these two equivalent elements one into the other. The quantity of heat which is called a *calorie* is, as every one knows, the amount required to raise 1 kilogramme (2·20 lbs. avoirdupois) of water

1° centigrade; on the other hand, mechanicians have called *kilogrammetre** the work done in raising 1 kilogramme to the height of 1 metre in 1 second of time. The problem solved consisted in determining how many kilogrammetres can be produced by 1 calorie entirely transformed into mechanical work; or, inversely, how much heat is produced at the expense of a given number of kilogrammetres. We know, at the present day, that 1 calorie is equivalent to about 425 kilogrammetres; and this number is called the *mechanical equivalent* of heat.†

We have seen what the heating power of the Sun is when expressed by calories or heat-units. We have seen what weight of water this quantity of heat would cause to boil; what a layer of ice it would melt at the surface of the Sun in the short space of one day; what a layer of ice would be melted at the surface of the

* A term now adopted in England and other countries, as well as in France.

† The names of the modern experimentalists who have strived to solve this important problem are Rumfort, Mayer, Joule, Thomson, Helmholtz, Hirn, Clausius, Regnault, and several others. But Mayer was incontestably the first to give a decisive answer to the question. [In England the unit of heat, or calorie, is sometimes stated to be the quantity required to raise 1 lb. of water from 60° to 61° Fahr., the equivalent of which in work is 722 foot-pounds; *i.e.* it will raise 772 lbs. to the height of 1 foot. But several of the most distinguished English and German writers have adopted the French expressions which will, doubtless, soon become universal.—P.]

Earth by that portion of solar heat which falls, in the space of a year, upon the globe. Now we are enabled to state what is the mechanical power of this immense source of heat; we can estimate the amount of force that all this heat incessantly supplied to us could generate at the surface of our globe if it was entirely converted into work.

In one year every square metre (1·19 square yard) on the surface of the Earth receives 2,318,157 calories; that is more than 23 thousand million calories per hectare (2·47 acres), or 9,852,200,000,000 kilogrammetres. Thus we see that the calorific radiations of the Sun, in falling upon a superficies of about 2½ acres, develope, under a thousand different forms, forces which are equivalent to the continuous work of steam-engines of 4163 horse-power. For the entire surface of the globe this sum of work is represented by 510 sextillions of kilogrammetres, or by 217,316,000,000,000 horse powers. 543 thousand millions of engines, each of 400 horse-power, working day and night without intermission,—such is the representation of the effect produced upon our planet alone by the solar rays.

A portion of this force is employed to warm the crust of the Earth to a certain depth; but, as the soil and the atmosphere radiate heat to space, and as the terrestrial globe appears neither to lose nor gain as regards its mean temperature, at least for a very long period of years, all this portion of the solar radiation

may be considered as maintaining equilibrium of temperature upon the globe.

Another portion transforms itself into molecular motion, into chemical action, which constitutes the source of vegetable and animal life. The heat which appears proper to these beings (animal heat, the heat of plants) is nothing more than an emanation of that of the Sun. 'Thus it is,' as Professor Tyndall has said, 'that we are not only in a poetical sense, but in a purely mechanical sense, the children of the Sun.' A little further on we shall have something more to say of solar action from this interesting point of view. Lastly, the calorific radiations of the Sun produce most of the phenomena of motion visible to the naked eye, of which the soil, the air, and the waters of the Earth, are constantly the theatre. This is easy to render evident.

To what cause, indeed, can we assign the aërial currents, those regular and irregular movements which we observe in the gaseous matter of the atmosphere? Evidently to solar heat, that only slightly warms the layers of our atmosphere, but which darts upon the soil of the tropical regions and raises them to a higher temperature than other latitudes. The lowest layers of air in contact with the soil are thus heated and dilated, the rarefied air thus produced ascends and flows to the north and to the south towards the higher latitudes, whilst it is replaced by masses of colder air

supplied by the temperate and polar regions. Thus are formed those regular currents of air known as *trade-winds*, the directions of which are, however, modified by the rotation of the Earth.

Two aërial rivers flow incessantly in each hemisphere from the equator towards the poles: the higher one flowing towards the north-east in the northern hemisphere, and towards the south-east in the southern hemisphere; the other, or lower current, taking precisely the contrary direction, and forming a stream from the north-east or south-east. 'Thus are produced the great winds of our atmosphere, which are materially modified, however, by the irregular distribution of earth and water. Winds of minor importance are produced by the local action of heat, cold, or evaporation. There are winds, formed by the heated air in the valleys of the Alps, which rush with destructive violence through the gorges of the mountains. There are agreeable puffs of breezes which descend from the glaciers on the heights. There are land-breezes and sea-breezes owing to variations of temperature upon the coast during the day and during the night. In the morning the heat of the Sun upon the soil causes a vertical ascension of air which the cooler air of the sea comes in to replace. In the evening the soil is sooner cooled by radiation than the water of the sea, and the circumstances are reversed: it is then the cooler and heavier air of the coast that flows towards the sea.' (Tyndall.)

The winds, therefore, have, all of them, for common origin the heat of the Sun exerting itself unequally upon the various regions of the Earth's surface, according to the position of our planet; this position, we know, varies unceasingly with the hour of the day and the period of the year. The rotation and translation of the Earth co-operate, then, with the radiation of heat by the Sun, to produce these currents of air in the atmosphere. A portion of the mechanical power of the ethereal emanations of the Sun is thus expended in producing visible motion.

But this is not all. The alternate heating and cooling of the soil and of the atmosphere produces at one moment evaporation from the waters of seas, rivers, and lakes; and at another, a condensation of the watery vapour contained in the air. When the vesicles which constitute clouds are cooled, they unite to form drops, which fall by their own weight to the ground in the form of rain. If the cooling is more intense, they congeal to form snow, which accumulates itself principally on the mountain-tops; in these higher regions snow is transformed into glaciers. The heat of the Sun melts again the congealed water of the fields of snow and ice, springs arise, and streams flow down the mountain side by the action of gravitation, and, uniting with the rain-water, form brooks and rivers. Water returns thus to the ocean, from whence the heat of the Sun had caused it to rise.

We see, then, that the circulation of water like that of air—those incessant motions so indispensable to the maintenance of life on the globe—acquires the mechanical force which gives rise to it, partly from the mechanical power of the Sun and partly from gravitation at the Earth's surface.

Other liquid currents, those which furrow the seas from the equator to the poles, are produced in the same manner: unequal temperatures give rise to unequal dilatations, to ascending and descending currents in the waters; evaporation produces a reverse effect by increasing the saltness of the sea where the solar heat causes this evaporation to be most considerable, that is, in the regions of the equatorial zone: hence arises a difference in the specific gravity of the waters and motion (or currents) which is the consequence of it.

The quantity of motion thus unceasingly produced by solar heat upon the surface of our globe is immense. It is not confined to the aërial, fluvial, or oceanic circulations; or, in other terms, these circulations themselves give rise to incessant modifications in the solid crust of the Earth. A slow but continuous degradation of rocks and strata, transport of sand, gravel, and mud, from year to year, and from century to century, change the form of our coasts, the shape of our hills and mountains. And it is still the mechanical power of solar heat which is the prime cause of all these transformations.

§ III.—The Chemical Radiations of the Sun.

Combinations and Decompositions produced by Solar Light.

It is not only in the form of heat and light that the Sun pours periodically upon the Earth its powerful and fertile emanations; the presence of its rays is manifest in yet another, less apparent, but no less efficacious form, and no less capable of modifying the substances submitted to their action: a multitude of chemical combinations and decompositions are effected by their influence.

This peculiar kind of activity inherent in the solar rays, was made evident for the first time by Scheele in 1770. This celebrated chemist discovered that white chloride of silver exposed to the light of the Sun took a dark violet tint. Since then the phenomenon in question has been studied and explained: it is simply a decomposition of the chloride of silver into its two elements, chlorine and metallic silver. Chloride of silver is not, however, the only chemical compound which solar light has the property of reducing; nitrate of silver, chloride of gold, and in general the chlorides, bromides, and iodides of metals not easily oxydisable, such as gold, mercury, silver, and platinum, are similarly affected. Under the continuous action of the Sun's rays, nitric acid, which, as every one knows, is

quite colourless, becomes yellow, whilst it loses some oxygen and evolves reddish vapours; the same reducing action occurs with a great number of other oxydised compounds placed in the same circumstances.

An experiment which is well known to all who have studied chemistry illustrates wonderfully this peculiar action of the Sun's light. We know that chlorine has a great affinity for hydrogen; a mixture of equal volumes of these two gases produces hydrochloric acid. When a lighted taper is plunged into the vessel that contains such a mixture, a loud detonation accompanies the combination of the two gases. But light can produce the same effect as the heat of the taper, and if the glass vessel containing the mixed gases be thrown into the air, in a place where the sun shines, a violent explosion ensues, and breaks the vessel into a thousand pieces before it reaches the ground. The light of the Sun is, therefore, capable of producing combination as well as decomposition. The latter example is not the only one of its kind; bromine acts like chlorine in contact with certain compounds of hydrogen; gum guaiacum is oxydised in the Sun's rays, and its colour changed from white to a dark blue.

Every one is aware how linen is bleached by spreading it over the damp grass, so as to expose it to the light of the Sun: this is another case of oxydation of organic compounds by the influence of the solar rays.

The production of the picture in the daguerreotype process and photography, — an art which has of late years been so immensely developed,— is based upon the effects of the solar rays upon certain substances which are very sensitive to their action. Moreover, a totally new branch of science called 'photo-chemistry,' has arisen from the researches made upon the chemical action of various sources of light, among which solar light is by far the most important.

Analysis of the Solar Rays.—Luminous, Calorific, and Chemical Intensity of the various parts of the Spectrum.

Every one knows, now-a-days, that the white light of the Sun is composed of a considerable number of tinted rays, among which seven principal colours can be easily distinguished, viz., red, orange, yellow, green, blue, indigo, and violet. The pencil or beam of white light that passes through a prism is transformed during its passage through this refracting medium into an elongated image showing the above-mentioned colours and known as a spectrum. This is the phenomenon called the dispersion of coloured rays, and is described in all elementary works on physics.

The investigation of the spectra produced by different sources of light has, of late years, revealed a great number of most important phenomena, but here we must content ourselves with those which concern more

particularly the Sun's light, and we must especially learn to distinguish, in its spectrum, rays which are characterised respectively by their *calorific*, *luminous*, or *chemical* effects.

When a beam of solar rays falls upon a given point before being decomposed by a prism, all these three kinds of effects are united, and the spot of light will produce heat, chemical and luminous effects, for the different waves of light are mixed up and act together. But when the same beam is caused to spread itself out and form a spectrum, that is, a long ribbon in which the rays are arranged one below the other in the order of their refrangibility, in which the different waves of light are separated according to their respective sizes, or, in other terms, according to the velocity of vibration which characterises each of them, we can study them from the three points of view just mentioned.

As early as the year 1800 William Herschel remarked that the various parts of the solar spectrum possess very different heating powers. He found that this property increased very notably by passing a thermometer from the violet to the red extremity of the spectrum; even beyond or above the red the temperature was found to rise, and only diminished at a certain distance from the visible extremity. It is not, then, the luminous rays which are the hottest, and among the solar rays there exist some which, though

incapable of acting upon our eyes to produce the sensation of light, nevertheless produce heat; beyond the visible portion of the spectrum there exists an invisible or dark portion situated above the red where the maximum of calorific action is found.

In 1781 when Scheele discovered the reducing *action of sunlight upon chloride of silver,* he found *that this compound* was *blackened more especially* at the extreme violet end of the spectrum. Dr. Wollaston went a little further still. He found underneath the violet an invisible region of the spectrum acting chemically upon certain substances, reducing them or oxydising them, which occupied a space equal to at least that which separates the violet from the red. M. Edmond Becquerel investigated these ultra-violet rays, and found that this portion of the spectrum, like the coloured portion, is traversed by a number of dark lines indicating points where certain rays are absorbed.*

In short, the solar spectrum appears to be formed of three parts, which are superposed, so that one more or less overlaps the other; one of these portions con-

* [Our readers will, perhaps, inquire how it is possible to detect these dark lines in a portion of the solar spectrum which is *invisible* to the eye. We may, therefore, state here, that this invisible portion below the violet can be rendered visible by causing the solar spectrum to fall upon certain solutions which are *fluorescent*, such as sulphate of quinine, decoction of horse-chetnut bark, &c. The peculiar phenomena of *fluorescence* have been very ably investigated by Professor Stokes, of Cam-

tains all those rays which act upon the optic nerve and produce the sensation of light—it is the visible and coloured portion of the spectrum, and has its maximum of intensity between the Fraunhofer lines D and E. Another portion is composed of heat-rays which commence in the violet where they are very weak, and pass

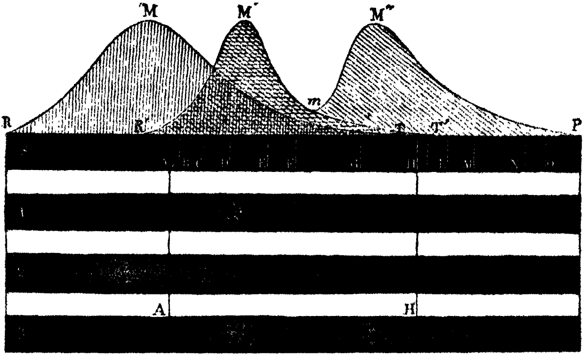


Fig. 4.—Heat, Light, and Chemical Spectra of Solar Light. 1. Heat Spectrum, R M T; 2. Luminous Spectrum, R′ M′ T′; 3. Chemical Spectrum, R′ M′ M″ P.

beyond the red extremity, at a certain distance from which they attain the maximum of intensity. Lastly, the third portion, whose action commences about the

bridge University. Phosphorescent bodies also shine in the ultra-violet region of the spectrum. For more ample details on this subject, see Phipson, 'Phosphorescence, or the Emission of Light by Minerals, Plants, and Animals,' p. 15, *et seq.* The invisible chemical spectrum is often spoken of as composed of *actinic rays.* Its dark lines are rendered evident by its photographic action.—P.]

region of the blue, goes on increasing towards the extreme end of the violet, and continues beyond the visible portion: the exact position of its maximum of intensity depends upon the nature of the substance submitted to its action. In our figure the curve of chemical intensity represents the action of solar light upon a silver plate covered with iodine, as in Daguerre's process.

However, they are the same waves of light, the same more or less rapid vibrations, which produce these varied effects: the only difference which exists between the different solar rays is the length of wave or undulation, which at one spot gives rise to calorific effects; at another, to effects of light and colour; and at a third, to chemical effects.

In the same way that we have sought to measure the intensity of the light and heat of the Sun on the surface of the Earth, we have endeavoured to estimate also the intensity of its chemical action. Two of our contemporary chemists, Messrs. Bunsen and Roscoe, have found that the power of the Sun, in this respect, can be represented by a volume of chlorine and hydrogen gas enveloping the Earth to a thickness of thirty metres (38·15 yards): in a single minute the action of the solar rays would transform this immense volume of gas into hydrochloric acid. Here again, as with heat and light, our atmosphere exerts a certain amount of absorption; under the normal inclination of the

solar rays, the layer of hydrochloric acid formed would be only 17 metres ($18\frac{1}{2}$ yards) thick; it would be reduced to 11 metres (12 yards) if the rays of the Sun are supposed to traverse the atmosphere at an angle of 45°.

In one year the layer of mixed hydrogen and chlorine gas which the chemical rays of the Sun would cause to combine on the entire surface of the globe would amount to a thickness of 4600 kilometres ($2841\frac{1}{4}$ miles). If this amount be converted into heat, it gives more than 4000 times the number of calories deduced from the heat-rays of the Sun, and yet we have seen above what an enormous amount of heat the terrestrial globe receives directly from the Sun in the course of a year.

We have now some notion of the power of the solar radiations, both those of heat and of light, and also those which occasion chemical action. It remains for us to sketch out the influence which these three combined exercise upon the organised beings which live on the surface of the Earth.

CHAPTER II.

INFLUENCE OF THE SUN UPON LIVING BEINGS.

Action of Solar Light on Plants—Evolution of Oxygen, retention of Carbon—Vegetation in the dark—Indirect influence of Light on Flowers—Vegetables are beings spun out of air by the Sun.

THE effects of solar heat on the Earth, studied from a purely mechanical point of view, have been seen above. We know that this heat is the cause which determines the movements of the atmosphere and the great currents of the ocean; that it raises vapour from the damp soil, from the seas and the rivers, which it causes to fall again as rain, hail, or snow. The power which, during a hurricane, snaps and uproots the largest trees, is borrowed from the Sun; it is a transformation of the heat-vibrations of its mass into a translatory motion of those gaseous molecules which compose the atmosphere of the Earth.

In phenomena of a purely physical order the transformation of the power of the solar rays is, we

may say, direct. The ethereal undulations caused by the vibrations of the Sun's mass, after spreading from the central orb to our planet with a velocity of some 185,000 miles per second, communicate to the molecules of the air an intimate motion which manifests itself to our eyes as a dilatation, and determines a change in the density of the gaseous mass. The equilibrium of the different layers is destroyed, gravitation tends to re-establish it and does the rest: the molecular motion changes into a motion of masses.

No doubt solar heat has another kind of influence on the globe. Since the time of Ampère our physicists have studied those magnetic streams which flow around the Earth as thermo-electric currents produced by the unequal distribution of solar heat over the Earth's surface, or by the action of the fused nucleus upon the solid crust of the globe. It appears certain, at any rate, that the diurnal, monthly, and annual variations of the compass, are intimately connected with the course of the Sun. Such is, in a few words, a sketch of the influence of the central orb upon inanimate bodies, and consequently upon the media in which organised beings are born, live, and die. Let us now enter into a few details with regard to the effects of the Sun upon life itself.

The beneficial and fruitful action of the solar rays upon living beings, both on vegetables and animals, is so evident, so well known and appreciated by every

one, that it appears almost superfluous to develope a thesis upon a subject which no one will attempt to contradict. But the manner in which this action exerts itself is less known,—that which is most generally ignored is the chain of intermediate phenomena by which the luminous, calorific, and chemical rays are capable of acting upon organised beings, and maintaining in them a source of life.

It is now about a century since Dr. Priestley in England, and Dr. Bonnet in Geneva, recognised the fact that the green parts of plants emit a gas which supports combustion,—oxygen gas. A little later Ingenhouz remarked that this oxygen was only emitted when the green parts of plants were exposed to the Sun; in the dark, on the contrary, they evolved carbonic acid gas. It remained to be learnt where the oxygen evolved by the leaves of plants came from. This was pointed out by Sennebier, and science was henceforward in possession of the following fundamental facts:—the green portions of plants exposed to the direct rays of solar light decompose the carbonic acid gas contained in the air, retain its carbon in their tissues, and set at liberty an equivalent amount of oxygen, that which, combined with the carbon, formed the carbonic acid. In the dark, on the contrary, the oxygen of the air is partly absorbed by the plant, and carbonic acid, produced by the oxydation of some of the vegetables' carbon, is evolved.

But this is not all. We know from the more recent researches of a learned American, Dr. Draper, that this decomposition of carbonic acid by plants is only operated by the luminous rays; neither the purely calorific rays, nor the chemical rays occasion the evolution of oxygen; 'but we must not hasten to conclude,' says J. Sachs, in his treatise on 'Vegetable Physiology,' 'that the chemical rays play no part whatever in the nutrition of the plant: before complete assimilation can take place there are many other steps to be taken besides the evolution of oxygen gas.' If clouds happen to intercept the light of the Sun the disengagement of oxygen gas is considerably slackened; the same thing occurs during twilight, and if the atmosphere be completely deprived of solar light—for instance, during a total eclipse—the phenomena of vegetation proceed as at night, carbonic acid is emitted instead of oxygen.

The differently coloured rays have not, however, the same reducing action upon the carbonic acid of the atmosphere: according to the researches of Daubeny, Hunt, Draper, and the recent experiments of M. Cailletet, three colours which are the most active in chemical decomposition—for instance, the violet, the blue, and especially the green—are precisely the least favourable to this decomposition. In fact, it appears to be proved that in the green rays of the spectrum leaves of plants actually secret carbonic acid. This

would explain, to a certain extent, the well-known fact that, underneath large trees, vegetation droops and languishes, even when the shade is not very intense.

Heat cannot supply the place of light in the important function of vegetation.* A plant which is shut up in a dark place, even when there is a sufficient degree of temperature, becomes chlorotic; its green colour disappears; it only lives and grows at the expense of its own substance. M. Boussingault has recently studied the phenomena of vegetation in the dark; his experiments prove that if the young plant raised from a seed be developed out of all contact with light, the leaves do not act as a reducing apparatus; a plant born under such circumstances emits carbonic acid constantly, as long as the substance of the seed can supply any carbon, and the duration of its existence depends upon the weight of this substance. It is a singular fact that a plant, developed in complete darkness with stalk, leaves, and roots, performs functions like an animal during the whole period of its existence. 'It is only under the influence of light that leaves are sensitive, endowed with periodic movements, and capable of motion.

* 'By the influence of light,' as Moleschott has truly remarked, 'the brilliant nights of the polar regions cause the crops to ripen in a short time, whilst many days of our summer heat cannot accomplish it.'

In the dark they are rigid and appear to be asleep.' (J. Sachs, 'Vegetable Physiology.')

Finally, if the development of the various colours of flowers be independent of the local action of light, the latter is no less indirectly the indispensable agent both of the formation and of the colours of flowers, since the corolla and the staminæ can only grow and subsist at the expense of substances formed in the leaves by the action of light.

'Leaves, flowers, fruit, are therefore beings spun from the air by light. When we contemplate their striking colours and their sweet perfumes causing a feeling of serene satisfaction in the poetic soul which lies dormant in the mind of every one, we are reminded that light is the mother of the colour and the perfume.' (Moleschott, 'Life and Light.')

We should not, however, combine these two phenomena, namely, the colour of plants and their odoriferous properties, for whilst the green colour appears to be a consequence of the exhalation of oxygen, it is, on the contrary, by oxydation that the essential oils which produce the perfume are formed. But this oxydation is itself accelerated by solar light; hence many flowers which scent the air during the day lose their perfume at night.

Effects of Solar Rays upon the life of Animals—Health of Man, and life in the Country.

If the solar rays, and among them the luminous rays, play so important a part in the phenomena of vegetation, it is evident that they cannot be less useful to animals. Indirectly they are absolutely necessary to them; for, after all, the vegetable kingdom supplies nutriment to the animal world. But the experience of every day teaches us what a great influence the light of the Sun has upon the health of men and animals: it is almost enough to compare those who pass the greater portion of their lives in the open air and in the sunshine with those who live in obscure dwellings, in narrow streets, and densely populated cities. Dwellings which are badly lighted, besides being damp, cold, and ill ventilated, are unhealthy from the mere fact that they are not vivified by the solar rays. But the kind of action which these rays exert in this case is quite distinct from their influence on plants. In the act of respiration animals consume oxygen, and exhale carbonic acid both day and night, although nocturnal respiration gives out less carbonic gas than the same function during the day. It results from this that animals produce precisely the gas which is necessary for plants, and the latter that which animals require for respira-

tion. It is not surprising, then, that life in the country and daily walks in the green woods are so essential to perfect health:—The leaves of the trees, the blades of grass, all the plants which cover the ground, exhale oxygen in abundance; in such circumstances, our lungs are filled with the purest and most vivifying air.

Dr. Moleschott has made numerous experiments which tend to prove that, taking everything into account, heat, atmospheric pressure, nutrition, &c., the quantity of carbonic acid exhaled by an animal increases with the intensity of light, and attains its lowest limit in complete obscurity. 'This is as much as to say,' he adds, 'that the light of the Sun accelerates molecular work in animals.'

The rays of the Sun are, therefore, from every point of view, the first condition of existence for organised beings on the surface of the Earth. They supply them with heat, without which life would soon be extinguished; with light, which presides over the nutrition of plants, and consequently over the lives of every being in the animal world; at every moment they determine numerous chemical combinations and decompositions. They constitute an incessant and periodically renewed source of movement, power, and life. Men of the present day profit not only by the prodigious quantity of force which the Sun annually pours upon the Earth in the form of

calorific, chemical and luminous undulations, but they are consuming also that which has been preserved for thousands of centuries. What are, in fact, the accumulated masses of coal buried in the crust of the Earth by geological action, but the produce of solar light condensed some thousand centuries ago in gigantic forests? Their carboniferous principle transformed by a kind of slow distillation amassed itself first into a peaty tissue, then into more and more compact strata, until the layers of vegetable remains were completely converted into basins of coal. At the present day, in our manufactories, our locomotives, and steamers, these precious fossils give back to man in light, heat, and mechanical power, all that they had formerly acquired for thousands of years from the rays of the Sun.*

Influence of the Sun on the Terrestrial Globe—Recapitulation of the foregoing facts—Religious conceptions of the Aryas.

In a page of his work on Heat Professor Tyndall has condensed, in an admirable manner, the data which we have given above regarding the influence of the solar rays. 'As certain as it is that the force which puts a watch in motion is derived from the

* [This sublime thought has been shown by Grove, Smiles, and other eminent writers, to have been first enunciated by our celebrated engineer, George Stephenson.—P.]

hand which winds it up, so certain is it that all terrestrial power is derived from the Sun. Without taking into account the eruptions of volcanoes, the flux and reflux of the sea, every mechanical action we observe on the surface of the Earth, every manifestation of power, organic or inorganic, vital or purely physical, has its origin in the Sun. Its heat maintains the sea in its liquid state, the atmosphere in a gaseous state, and all the tempests which agitate the one and the other can be traced to its mechanical force. It attaches to the sides of the mountains, the sources of rivers, and the glaciers; and consequently cataracts and avalanches precipitate themselves below with an energy which is derived immediately from the Sun. The thunder and the lightning are another manifestation of its power. Every fire that burns, and every lamp that shines, expend heat and light which originally belonged to the Sun. At the period in which we live, alas! we are forced to become familiar with what occurs on battle-fields, and we find that every charge of cavalry, every shock of arms, makes use of, or rather abuses, the mechanical force of the Sun. Sunshine comes to us in the form of heat, it leaves us in the form of heat, but between its coming and going it has awakened various forces of our globe. All these are special forms of solar force, so many moulds into which it has temporarily entered its progress from its source to the

infinite. When presented to our minds in their true aspects, the discoveries and generalisations of modern science constitute the most sublime poem which has ever been offered to the intelligence and imagination of man. The physicist in our days is constantly in contact with marvels that would have caused Milton to grow pale; marvels so grand and so sublime that he who contemplates them requires a certain force of character to preserve him from being completely dazzled. Consider the entire energies of our world, the power shut up in our coal-fields, our winds, our rivers, our fleets, armies, and cannons. What is it all put together? A minute fraction of the Sun's power equivalent at most to a 1-2,150,000,000ths of its total energy. Such is, indeed, the portion of solar force absorbed by our Earth, and still we only convert a minute portion of this fraction into mechanical power; in multiplying the whole amount of our energy by millions of millions we should not be able to represent the total expenditure of solar heat.'*

In presence of these deductions of modern science, now incontestably proved, and which can only be developed or extended by its future progress, it is impossible not to be struck by their resemblance to certain primitive religious conceptions which form the basis and the substance of all religions and all

* Compare Tyndall, 'Heat as a Mode of Motion.'

kinds of worship both ancient and modern. The adoration of fire and sun-worship were naïve representations of a profoundly true idea—that according to which all terrestrial power, movement, life, and thought, has for common origin the calorific, luminous, and chemical rays of the Sun. M. Burnouf, in his learned researches on the 'Science of Religions,' places this truth in a very clear light. Let us quote a few passages.*

'In looking around them,' he says, 'the men of that time (the Aryas) perceived that all the motions of inanimate things on the surface of the Earth proceeded from heat which manifests itself either in the form of a fire that burns, or in the form of lightning, or again as wind; but lightning is a fire hidden in the clouds and rises with them into the air, whilst the fire which burns is, before it manifests itself, shut up in the vegetable matters which feed it; lastly, wind is produced when the air is set in motion by the heat which rarefies it and causes it to condense again when it is withdrawn. Plants, in their turn, derive their combustibility from the Sun, which causes them to grow by accumulating its heat in them, and the air is heated by the rays of the Sun; the same rays reduce the terrestrial waters to invisible vapours, then into clouds which carry lightning. The clouds drop

* Burnouf, 'Revue des Deux Mondes,' 15 April, 1868.

as rain, give rise to rivers, supply the seas which are upheaved and troubled by the winds. Hence all this motion which animates Nature around us is the work of heat, and this heat proceeds from the Sun which is at once the "celestial traveller" and the universal motor.

'Life also appears to them intimately connected with the idea of fire . . . . The grand phenomena of the accumulation of solar heat in plants, which science has since brought to light, was perceived very early by ancient races of men; it is many times mentioned in the *Veda* in very expressive terms . . . When they lighted the wood on the hearth they knew that they only forced it to give up the fire which it had received from the Sun. When their attention was arrested by animals, the intimate connexion between heat and life appeared to them in all its force; heat maintains life; they knew no living animals in which life existed without heat; on the contrary, they found vital activity developed or diminished according as the animal received more or less heat . . . Life only exists and perpetuates itself on Earth in three conditions, because fire penetrates bodies in three forms, one of which resides in the solar rays, another in igneous aliments, and the third in respiration which is air renewed by motion. But the two latter proceed each in its own manner from the Sun (sûrya); its celestial fire is therefore the universal motor and the

father of life; its first-born was this lower fire (agni) produced from its rays, and its second eternal co-operator is the air in motion which is also called wind or spirit (Vâyu).'

Finally, 'Nowhere does thought manifest itself without life. Moreover it is only met with in beings where life is highly developed, such as animals. Now when an animal dies, his limbs yield, and he falls to the ground, becomes motionless, ceases to breathe and loses heat; with life his thought escapes. If it be a man all his senses are annihilated; his mouth, pale and cold, is no longer capable of pronouncing a single word, from his sunken chest issues no sound expressing joy or grief; his hand presses no longer that of his friend, his father, or his child; all signs of intelligence and feeling have vanished. Soon after his body is decomposed, liquefied, evaporated, nothing remains on the earth but a black spot and a few bleached bones. But thought, where is it? If experience has shown it to be indissolubly attached to life, so that when life is extinguished thought is extinguished also, some may think that thought has the same destiny as life, or rather, that the principle which thinks is identical with the living principle, and does not exist in duality with it; but life is heat, and heat originates in the Sun. Hence fire is at once the motor of all things, the agent of light, and the principle of thought.'

Doubtless the authors of these speculations on the first principles of things in general did not conceive their ideas with the same clearness which, in the present advanced state of knowledge, is permitted to the analytical grasp of modern reason; but is it not a marvellous thing to witness the circle that was opened thousands of years ago by intuition closed to-day by the light of science?*

* [In quoting the above passage from M. Burnouf, and referring to Professor Tyndall's idea, both of whom believe that everything on earth is derived from the Sun—that all we are, all we possess, can be directly or indirectly traced to the influence of the central orb of our system, the author has somewhat overlooked the fact that a certain portion of the external influence which affects our tiny globe is derived, not from the Sun, but from other bodies revolving in space. He has actually shown, in a former passage of the present work, that the quantity of heat derived from space by our Earth is equal to about five-sixths of that which we receive from the Sun. We are, therefore, much more intimately connected with the UNIVERSE than some philosophers appear to believe, and there can be no doubt that our Sun is dependent for its various 'powers' or 'forces' upon other distant bodies, as we are, to a great extent, dependent on it.—P.]

CHAPTER III.

The Sun in the Planetary World.

§ I.—Position and Influence of the Sun in the Planetary System.

Apparent diurnal Motion of the Sun ; Rising, Setting, Passage across the Meridian.—Apparent annual Motion of Translation ; Reality of the Earth's Motion.—The Sun is the common Focus of the Orbits of all the Planets.—Enumeration of the three Groups of Planets belonging to the Solar World and of their Satellites.

We have just seen what the Sun is to the Earth, and to the animated beings which people its surface: its heat, its light, its chemical activity, essential conditions of all motion, of all vegetable and animal life, have been investigated by us before we knew anything of the source from which they all emanate—without knowing what the great orb is that thus communicates to us, as it were, a fraction of its own power. We have hitherto interrogated Physics only, and yet, by the aid of that branch of science, we have been able to

lift a portion of the veil which hides from us the cause of the Sun's eminently beneficial and fruitful influence. These effects, before they were rigorously investigated, were very imperfectly known, but now we can connect the more important of them with the different kinds of solar radiations; we know that very different parts are played by the rays of the Sun according as they manifest themselves to us as light, heat, or chemical activity.

Now we must go still farther, and make use of another branch of knowledge. Let us address ourselves to Astronomy, and ask this Science not what function the Sun performs towards the Earth, but what this great orb does in the heavens, at what distance it is placed from our globe and from other planets or stars, what are its dimensions, its form, its various motions, what is, in fact, its physical constitution? Many of these questions are now solved, and others are hanging in suspense between this or that hypothesis, still devoid of sufficient proof to lead us to certain conclusions, whilst others, again, are scarcely expected to be solved for many years to come. To tell the truth, the minds of very few men are occupied with such problems. The Sun is seen everyday, or nearly so, seen rising or setting, or going its daily round in the sky, rising higher or lower above the horizon according to the season of the year; it is welcomed joyously, or the heat of its rays is complained

of; but that is all. An entire life is passed away without once inquiring the why or the wherefore of so many wonderful phenomena returning perpetually at regular intervals, and looked upon with indifference as matters of common occurrence. It is the same thing here, however, as in many other cases where curiosity is only excited after a certain degree of reflection, or, as D'Alembert expresses it in the 'Encyclopedia,' 'It is not without some reason that the philosopher is astonished that a stone should fall to the ground; people laugh at his astonishment, but after a little reflection they join in it themselves.' Let us reflect a little whilst observing what is going on around us, let us question the phenomena we observe, and we shall soon have as much cause to be astonished as the philosopher.

We may commence by stating accurately the position of the Sun with regard to the Earth and to other similar orbs, that is, with regard to the various planets.

Every day in the year, in our latitudes, we see the Sun rise on our eastern horizon, mount gradually in the sky to a maximum altitude, which varies according to the day of the year, but which, each time, marks noon, or the middle of the day; then, from this point, the summit of its daily course, we see it descend, and finally set below our western horizon. So far the Sun is endowed with the same appearances as the stars and the Moon; and now-a-days no one ignores that this general

motion of the stars is not real, but a natural consequence of the Earth's daily rotation from west to east. The terrestrial globe turns upon itself around an axis whose position is invariable, and with a uniform velocity in $23^h\ 56^m\ 4^s$.*

When the Sun rises, it is, therefore, our horizon which, carried along by the rotation of the mass to which it belongs, descends towards the east before the disc of the Sun; when the Sun sets it is also our horizon which, by rising towards the west, soon masks the radiant orb from our view.

Another apparent motion, which can be easily noticed by those who are somewhat familiar with the aspect of the starlit sky, appears to carry the Sun progressively in a precisely opposite direction to its apparent daily course, that is, from west towards the east. We can verify this second kind of movement in the following way. At any given period of the year let us take note, at midnight, of the aspect presented by the various constellations; for instance, let us observe at that moment what stars are in the plane of the meridian, that is to say, in the same plane that the

* This is the length of the *sidereal day*; the *mean solar day* is longer by 3 minutes and 56 seconds, for it is 24 hours. It is the interval which elapses between two successive passages of the Sun over the meridian. Whilst the length of the sidereal day is invariable, that of the solar day varies throughout the year; hence astronomers have recourse to an average interval called the mean solar day.

Sun occupies at the opposite side of the heavens at the same moment. On the following nights, at midnight precisely, the same stars will be found to have passed from the meridian towards the west, and their progression in this direction will be seen to be about four minutes ($3^m\ 56^s$) each day. This amounts to saying that the stars now opposed to the Sun are more easterly than the first, or that the Sun itself occupies in the heavens more and more westerly constellations with regard to the Earth. In one year the Sun appears thus to circulate entirely round the sky in a plane which is inclined to that of the Earth's equator about $23° 27'$.

In reality this motion does not belong to the Sun. Since the time of Copernicus every one knows* that it is the Earth which is thus carried along in the course of the year, describing round the Sun a nearly circular orbit. The exact duration of this revolution is $365^d{\cdot}2564$, so that after this interval of time the Earth

* 'Every one knows' is an expression which is not exactly in accordance with history. We have only to call to mind the persecution of which the great Galileo was the unfortunate victim, to perceive with what reserve the most enlightened minds accepted the new ideas concerning the Earth's double motion. Up to the middle of the eighteenth century, in France itself—not in Italy and Spain where the Inquisition was rampant—authors hesitated to declare their opinions on this subject; they scarcely dared to present the system of Copernicus otherwise than as a conjecture.

and the Sun are found once more in a straight line with the same star.

This is not the place to show how these two movements, the rotation and translation of the Earth, are capable of explaining the alternate occurrence of day and night, their unequal lengths in different latitudes, their variations in the course of a year, and finally the different heights of the Sun above each horizon according to the season of the year.

But that which we particularly wish to insist upon is the situation of the Sun with respect to the Earth :—our planet describes, as we have just said, an almost circular curve. This curve or orbit, the plane of which is called the ecliptic, is in reality an ellipse, an oval curve, symmetrical with regard to two unequal axes, and having its centre C, fig. 5, at the point of intersection of these lines. The Sun occupies a point on the greater axis, but not the centre; it is situated in S, at one of the *foci* of the curve. It results from this that the distance of the Earth from

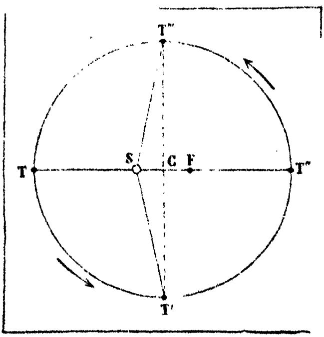


Fig. 5 —Elliptic Orbit of the Earth.—

stantly throughout the year. At T, the extremity of

the longer axis nearest to the Sun, the Earth is at its *perihelion*, which happens about the 1st January: at T$''$, the other extremity, corresponding to the 1st July, it is at its *aphelion*, or its greatest distance from the Sun. Lastly, at each extremity of the smaller axis, when the Earth is at T$'$ and T$'''$, its distance from the Sun is the *mean* between these two extreme distances, a state of things which occurs about the 1st April and 1st October.

The Earth is not the only orb which revolves in this manner round the Sun. 132 bodies, planets, and satellites, form the planetary *cortége*. (At least, such is the number of these bodies actually known.)

In the first place, we have eight principal planets, which can be divided into two groups; the group of planets of medium size, which, taken in the order of their distances from the Sun, are Mercury, Venus, the Earth, and Mars; and the group of large planets, Jupiter, Saturn, Uranus, and Neptune. Between these two groups circulate a number of very small planets, which can only be seen with a telescope, the number of which is increasing every year by new discoveries, and at the present day (February 1869) 106 of these minor planets may be counted. Besides these 114 planets, we must reckon 18 satellites:—the Moon, which revolves round the Earth and, with the Earth, round the Sun; the four satellites which in like manner accompany Jupiter, the eight satellites of

Saturn, the four belonging to Uranus, and the one pertaining to Neptune.

Such is the composition of our planetary system. Each planet describes round the Sun an elliptic orbit like that of the Earth, so that the Sun occupies the common focus of all these curves. These orbits are almost perfectly plane, and only slightly inclined one to another. Let us take this opportunity of stating that the duration of planetary revolutions increases with the mean distance of the different planets from the Sun, according to a law the discovery of which we owe to Kepler; that these intervals are comprised between 88 days, the year of Mercury, and 165 years, the duration of Neptune's revolution (its year). These data will suffice to enable us to gain some idea of the situation occupied by the Sun in the midst of these secondary orbs to which it distributes heat and light.

The Planetary World as seen from Space: its Dimensions in length and breadth.—How far those Comets penetrate it whose Orbits have been approximately calculated.

Let us imagine an observer travelling in the depths of space, to such a distance from our planetary world as would enable him to embrace the whole of it in one view. If the direction taken by him be that contained in the plane of the Earth's orbit, or in that of any other planetary orbit, he would see a brilliant star, shining very brightly, and on each side of it a hun-

dred smaller stars, some lost in the bright rays of the central star, others far enough from it to allow them to be more easily distinguished; all of them, however, infinitely less bright than the Sun,* and varying in brilliancy according to their apparent distances from the latter. All these satellites of the Sun would be seen to oscillate about its disc, describing, to all appearance, right lines or nearly so, as we observe to be the case with the satellites of Jupiter, which we see move from one side to the other of that planet. Some would appear to move with great rapidity; they would be those nearest to the central star: Mercury, Venus, the Earth, and Mars. The others would describe their courses much more slowly. The whole would present the aspect of a lenticular mass of stars, or, if the distance of the observer were too great to allow him to distinguish the different luminous points, of a bright star surrounded by nebulous matter of an elongated form.

As for the dimensions of the planetary system, at least as we know them at the present time, it has a diameter equal to sixty times the distance of the Sun from the Earth, or about 5700 millions of miles. If we desire to form some idea of this immense extent of space,

* To tell the truth, a great number would be really invisible, some on account of their minute size, others because their light would be confounded with that of the Sun. But we are indulging in a supposition here.

we must estimate it by the time which certain bodies would require to pass through it. Light, which progresses at the rate of 180,000 miles per second, requires 8 hours and 17 minutes to travel from one end to the other of the planetary system; as for a cannon-ball, if it continued to travel with a uniform velocity of 495 yards per second, it would take no less than 626 years; sound would require 845 years to travel over the same distance.

The thickness of planetary space is much less extensive than its length. In considering it represented by a line perpendicular to the plane of the Earth's orbit, we find it nineteen or twenty times less than the dimensions of the long diameter, or about 300,000,000 of miles.

In all this we have said nothing of comets. These bodies move round the Sun like the planets; but their orbits are much more elongated, and have all kinds of inclinations on the plane of the ecliptic. Moreover, the direction of their motion is retrograde in some cases, direct in others. If we consider only those comets, the elements of whose orbits we have been able to calculate with tolerable accuracy, and which certainly belong to our solar system, the dimensions of the latter become much greater than those of the planetary world properly so called, limited by the orbit of Neptune. Indeed, whereas the radius of Neptune's orbit is equal to thirty times the mean distance from

the Sun to the Earth, the aphelion distance of the comet of 1844, whose period is a hundred thousand years, is lost in extra-planetary space at a distance four thousand times as great.

There can be no doubt that, among the numerous comets whose very elongated orbits appear, as long as they are visible to us, to be arcs of parabola, some travel even farther than this from the Sun. But without going beyond what is known and determined, we see that the solar world extends from the common focus to a distance of some 375 thousand millions of miles, and probably even to a greater distance than this. From a point of space so prodigiously distant as that at which we find the comet whose period is a hundred thousand years when at its aphelion, the Sun would only appear like an ordinary star: its brilliancy would, it is true, surpass that of the brightest stars known, but its apparent diameter would be scarcely half a second.

It is sufficient for the present to get a glimpse of the Sun in the midst of the stars (planets) which circulate round it in closed orbits, and to note to what a distance the sphere of its activity extends; presently we shall have the opportunity of stating the position which it occupies among other stars (fixed stars), and the connexions which, in all probability, bind it to the sidereal world. We shall then see that our Sun forms part of an association of countless suns similar to itself,

and that a movement of translation carries it along with its entire train of planets, &c., and causes it to describe an immense orbit around some centre yet unknown.

§ 2.—Form and apparent Dimensions of the Sun.

What is the Form of the Solar Disc?—The Sun at the Horizon; its Doubly Elliptic Form; Fantastic Forms caused by Refraction in Layers of Vapour.—Various Means of observing the Sun without wounding the Eye.—Helioscopes.—Projection of the Sun's Disc into a Camera Oscura.

The light of the Sun is so dazzling that, as every one knows by experience, it is almost impossible to look at it with the naked eye when it shines in a clear sky devoid of clouds, and at a certain distance above the horizon. On the horizon itself (that is to say, at the moment of sunrise or sunset,) this difficulty is no longer experienced, and we may, without hurting our sight, acquire a notion of the apparent form of its disc. The very great diminution of the luminous intensity of the solar rays when the Sun is seen at the horizon, is explained very simply as follows:—Every ray of light which comes to us from space and reaches our soil must pass through the Earth's atmosphere; it is the more absorbed by the air the greater the distance that it travels and the denser the air through which it passes. Now, if we admit that the atmo-

sphere extends vertically to a height of 62 miles, a ray of light coming from the zenith has only these 62 miles to pass through before reaching our eye, whilst at the horizon the distance travelled would be 706 miles, and

Fig. 6.—Deformation of the Sun's Disc by Refraction.—Elliptic Form of the Sun at the Horizon.

through the densest portions of the air. In fact, Bouguer found that the intensity of solar light is one thousand times less when the Sun is 1° above the horizon than when it has risen 40°: this result is,

nevertheless, only approximative, and depends very much upon the state of the atmosphere and its purity on the day of observation.

However that may be, there is never any difficulty in looking at the Sun when it is very near to the horizon. We see it then in the form of a well-defined circular disc. But this disc, instead of being a perfect circle, as we shall see it should be, is more or less flattened, especially on its under side; it appears as an oval, which, moreover, is not regular, but formed of the halves of two ellipses A C B and A D B (fig. 7), having the same greater axis A B, but the smaller axes C O and O D are unequal. This peculiar deformation is caused by the refraction of light as it passes through the atmosphere, the effect of which is to elevate the various points of the limb or border of the disc so much the more the greater their proximity to the horizon.*

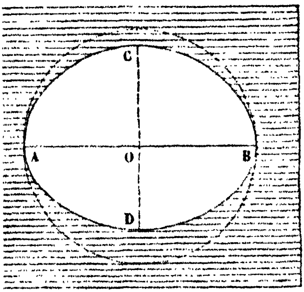


Fig. 7.—Double Elliptic Form of the Sun at Sunrise and Sunset.

* [In other terms the thicker the layer of air traversed by the ray of light, the greater the refraction.] 'On high mountains and on plateaux near the sea-coast this flattening of the disc

Sometimes want of homogeneity in the atmospheric layers is caused by admixture of vapour, and is such that the deformation of the solar disc by refraction renders it unrecognisable. Fig. 8 represents some of these appearances observed from the coast at Dunkerque by Biot and Mathieu. Certainly these are not the

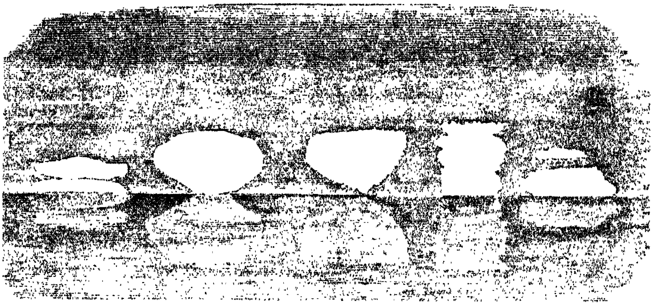


Fig. 8.—Singular Appearances of the Sun at the Horizon, as observed by Biot and Mathieu at Dunkerque.

circumstances in which we should be placed to acquire an exact notion of the form of the Sun. Let us state, then, in a few words, the cases in which this form can be properly seen, and let us describe the artificial means resorted to by astronomers to investigate as long and as minutely as possible the different portions of its disc.

appears very considerable; it attains sometimes to 1-5th the apparent diameter of the Sun. The disc of the Moon presents the same phenomenon.' (Biot, 'Astronomie Physique.')

Light clouds, or even fog sufficiently dense, sometimes absorb so much of the Sun's light that we can see through them the form of the disc thoroughly defined and perfectly circular; its colour, most frequently reddish yellow, is sometimes of a dead white, *so slightly dazzling that the naked eye supports its glare without the slightest fatigue. If this happens* at a *time of* day when the Sun is high above the horizon, atmospheric refraction does not interfere much with its true form, and unless we apply very rigorous measures we cannot then recognise any deformation.

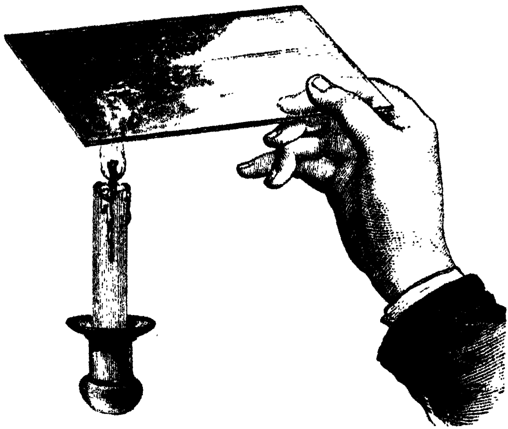


Fig. 9.—How to Blacken a Glass in order to observe the Sun during an Eclipse.

But we have here a very simple process by which we can at all times produce the effects of the clouds or

the fog above mentioned,—a process which is frequently made use of when an eclipse of the Sun is observed by unaided sight. We take a piece of window pane, or rather, a piece of plate-glass with perfectly plane and parallel faces, which we hold for a *few instants above the flame of a candle or a lamp. A layer of lamp-black is thus deposited upon the glass* and suffices to diminish the intensity of the solar rays; but as it is difficult to obtain in this manner an equal layer of black, the disc of the Sun seen through a smoked glass has not an uniform brightness, therefore the use of coloured glass is generally preferred.

Coloured glasses were used for observing the Sun before telescopes were invented. 'Apian tells us in his "Astronomicum Cæsareum," printed in 1540, that in his time several persons made use of various combinations of COLOURED GLASSES cemented together by their edges.' Arago, who cites this fact, 'is surprised, and naturally so, that such a simple method was so long in becoming generally adopted, and more particularly, that, after the invention of telescopes, an astronomer like Galileo should not have had recourse to it. Coloured glasses would, probably, have preserved this illustrious man from the affections of the eye which he so often suffered, and from the complete blindness which attended his latter days.' In fact, dangerous as it is to look at the Sun with the naked eye, this danger is infinitely greater when a telescope is used, even one which mag-

nifies to a slight extent only. We shall see presently what means are resorted to in this case.

The Sun may also be viewed by the naked eye by looking at it through a pin-hole in a card; the quantity of light which passes through this small opening is so slight that the brilliancy of the image is diminished enormously; but in this case the image is far from perfect. Reflection from the surface of a sheet of water, or from a blue or black-coloured liquid, also weakens the intensity of the Sun's light considerably. But the mobility of a liquid is such that the slightest breath of air ripples its surface, and renders its use for this purpose very inconvenient.

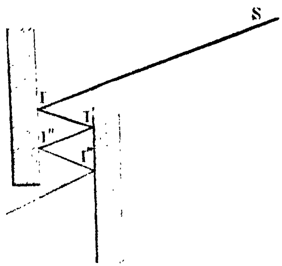


Fig. 10.—Diminution of Solar Light by a series of Reflections.

When the eye is placed behind two pieces of black glass parallel to each other, it receives the solar rays, which, after falling upon the first glass, are reflected on to the other, then back again on to the first, and so on several times; there are four reflections, I I′ I″ and I‴ (fig. 10). The absorption of light is such at each reflection that when it finally reaches the eye the image of the Sun can be seen without paining the observer. Opticians,

by placing these glasses into a little box with blackened sides, construct a small apparatus which is very convenient for observing eclipses of the Sun. They also manufacture for the same purpose what are called *helioscopes*, which are merely composed of two prisms, or two pieces of glass cut wedge-shaped, one white and transparent, and the other black or coloured; they are put together as shown in fig. 11. The image of the Sun seen through this helioscope is more or less weakened, according as it is seen through a greater or less thickness of the black glass; at S′E it is brighter than at S E: with this apparatus, therefore, we can follow an eclipse through all its phases by choosing the degree of absorption which best suits the sight.

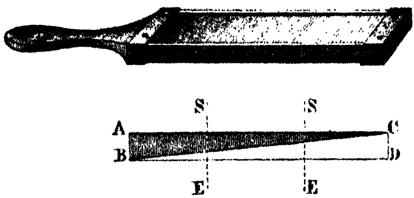


Fig. 11.—Wedge-shaped Helioscope.

M. Babinet, in his 'Notice on the Solar Eclipse of July 1860,' gives us another method for observing an eclipse, which renders it needless to look at the Sun at all, or even to leave our room. By this method 'an invalid can follow the phenomenon in question without rising from his bed.' It consists in placing in the sunshine a fragment of looking-glass, in such a manner

as to reflect the image of the Sun upon the ceiling or upon the walls of the room.*

A method which is preferable to the above, because it gives a neater and more vivid image which is not too bright, is that formerly employed by Fabricius, of whose works we shall have to speak presently. It consists in causing the Sun's rays to enter the small aperture of a camera oscura, where they are received upon a sheet of white paper, placed in such a position that the rays fall perpendicularly upon it. On this screen the reversed image of the Sun is then seen, which is larger and fainter the farther the sheet of paper is from the aperture of the camera. Galileo and Scheiner made use of this device; it was also employed by Gassendi to follow the passage of the planet Mercury across the Sun's disc on the 7th Nov. 1631.

Observation of the Sun in Refractors and Telescopes.—Danger to the Eye.—Use of coloured Glasses.—William Herschel's Method.—Polarising Helioscopes.—Foucault's Siderostat.—Silvered Objective Glasses.

Since the naked eye is liable to be hurt by solar light, unless the latter be weakened by the aid of some

* [We have often repeated this experiment; those who would also do so must be careful to take a very small piece of mirror, or, if they use an ordinary looking-glass, cover its surface with a sheet of paper having a small circular hole cut in its centre.—P.]

natural or artificial process, it is evident that the danger is much greater with regard to the image of the Sun produced at the focus of a refractor or a telescope. The concentration of the rays of light and heat, which unite to form the image at this focus, increases its brilliancy according to the power of the instrument: even with an instrument of small power the eye would be dazzled and burnt, if we did not take the precaution of weakening the intensity of the image. The first persons who made observations of this kind, Fabricius, Galileo, Harriot, for instance, only observed the Sun, with the newly-discovered telescopes, when it was near the horizon, or through a fog or a cloud of sufficient density. Even then they were obliged to be very cautious: Fabricius recommended that a very small portion of the solar disc should be at first admitted into the instrument, so that the eye might become gradually accustomed to the glare of the entire disc. They also studied the image of the Sun reflected from a sheet of water or from a somewhat dull mirror. In 1611, however, Scheiner made use of coloured glasses: he placed before the objective glass of his refractor a flat, coloured glass, finely polished, and with sides perfectly parallel, so that the form of the image was not distorted.

But even with all these precautions, the prolonged study of the Sun is highly dangerous to the sight, and many astronomers have suffered from it; Galileo and

Cassini died blind. William Herschel, who was as ardent an observer as he was profound in his philosophical views, made several researches with the view of finding out what substances it would be best to use for weakening the image of the Sun in the telescope and protecting the sight. He soon found that the particular colour of the glass was a matter of great importance: *red* glass absorbed the most luminous rays well enough, but it allowed a great quantity of heat-rays to pass, which in time occasioned serious inflammation of the eye; *green* glass was found to absorb the heat-rays, but allowed too much light to pass. Herschel recommended that coloured glasses should be replaced by black writing ink, diluted with a little water and filtered. This liquid possesses the property of absorbing equally the rays of different colours of which solar light is composed, so that seen through it the image of the Sun appears perfectly white. Moreover the greater portion of the heat-rays are extinguished.* The liquid was placed in a little vessel in front of the ocular glass. This simple apparatus has never been adopted.

At the present day astronomers use dark glasses,

* [We have examined the spectrum given by the liquid above described. It is characterised by a general absorption like that observed with a decoction of wall-flowers (*Cheiranthus*), but more especially in the violet between H and G, a little above F in the blue and about C in the red.—P.]

either black or blueish black, which are screwed on to the instrument in front of the ocular. They are generally $1\frac{1}{2}$ to 2 millimetres (4-100th to 6-100th of an inch) in thickness; but the use of these glasses is not without serious inconvenience. As the investigation of the inequalities observed on the Sun's surface requires instruments of great optical power, it often happens that if the observation be prolonged for any length of time, the dark glass becomes heated and cracks, suddenly exposing the delicate nerve of the eye to the full glare of the Sun's image.

Sir John Herschel first suggested the utility of polarising the light which enters the instrument, as this phenomenon was known to extinguish certain rays, and so to construct a new kind of astronomical eye-glass. Polarising helioscopes have been manufactured by Colonel Porro and by Herr Merz, and have realised the ideas of the illustrious English astronomer: they have this particular advantage, which coloured glasses have not, namely, that when adapted to the instrument, they preserve the natural colour of the Sun's image.

Castelli, a pupil of Galileo, imagined another method which is still in use at the present day. It consists in projecting the Sun's rays, after they have passed through the eye-glass of the telescope, on to a sheet of white paper. It is this method (somewhat similar to the projection of the rays into a camera oscura before noticed) perfected, and applied to an

equatorial refractor that enabled Mr. Carrington to make numerous interesting observations to which we shall refer again: the image of the Sun upon such a screen had a diameter of 28 or 30 centimetres (about 1 foot). Padre Secchi also employed it to measure the relative intensities of light at the border and the centre of the solar disc: with an objective glass of 6 inches in diameter he thus obtained an image of the Sun, which, received upon a diagonal reflecting ocular glass and thrown upon the screen of white paper, had a diameter of no less than 2 metres ($7\frac{1}{2}$ feet).

In order to study the Sun or any other celestial body in a continuous manner, M. Léon Foucault imagined an apparatus called a *siderostat*, which his premature death did not allow him to complete. According to M. Henri St. Claire Deville the instrument may be thus described:—'The siderostat is essentially composed, 1st, of a plane-silvered mirror, set in motion by clockwork, so as to project the rays of the Sun, or other star, in a constantly horizontal direction; 2nd, of a fixed objective apparatus, either a refractor or a reflector (that is, a refracting telescope or a reflecting telescope) which brings these rays to a focus. This focus is precisely at the aperture of a camera oscura, in which the astronomer, perfectly at his ease, records his observations or effects his measurements without the slightest fatigue or inconvenience. . . . One of the most interesting applications of the siderostat was

that which Foucault intended to make with it, viz., a permanent investigation of the Sun. In one of the rooms of the Observatory, which is more frequented than others, he wished to place an apparatus of this kind, which would throw upon a screen, ruled with lines crossing at right angles, a fixed and magnified image of the Sun. The apparition and forms of the *spots, the passage of a planetary body across the disc, &c., would thus be made the subject of constant study,* which could be carried on without the slightest danger to the eyes, and by all the persons whose occupations cause them to pass frequently through this room.'

To conclude what we have to say of the various means of observing the Sun without injuring the eyesight, we must mention another method, also due to Léon Foucault, but which, more fortunate in this respect than the siderostat, has actually been tested by experiment. This new process is only applicable to refracting telescopes, and consists in silvering the external surface of the objective glass. By this means the instrument is protected from the heating power of the solar rays, which are almost entirely reflected towards the sky, whilst a minute quantity of blueish light passes through the thin film of metal, is refracted in the ordinary manner, and forms at the focus of the instrument a perfectly pure image which may be observed without the slightest danger. The trial of this method of observation was made lately at the Paris

Observatory, with an objective of 10 inches diameter, and with complete success. It has only one drawback, —that of sacrificing the instrument to this kind of observation only; but this source of inconvenience does not exist for observers who devote themselves entirely to the study of the Sun.

Completely circular Form of the Solar Disc.—Its apparent Dimensions at different Periods of the Year.

We have insisted, perhaps, rather too long on the various methods of solar observation, but this digression was necessary to save those of our readers who may feel disposed to study the Sun, or even to inspect its disc out of pure curiosity, from the use of improper means, and accidents that might have been the consequence.

Let us now proceed with our subject. We have already seen that the solar disc has the aspect of a luminous circle, except when its image is deformed by refraction. Measures that have been made with the aid of instruments called *heliometers*, prove that the diameters of the Sun's disc are perfectly equal. Not the slightest indication of flattening has been detected on any side.

The apparent dimensions or angular measurements of this disc are very nearly those of the Moon; sometimes smaller, sometimes rather larger than the latter,

hence the eclipses of the Sun produced by interposition of the obscure disc of the new Moon, are sometimes total, sometimes annular. Its apparent diameter is rather more than half a degree; but it varies

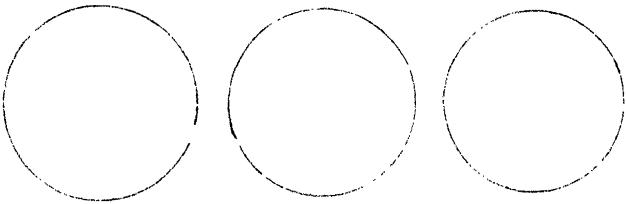


Fig. 12.—Apparent Dimensions of the Sun's Disc at the Periods of *Perihelion*, *Aphelion*, and at its *mean Distance* from the Earth.

with the period of the year, because, as the Earth describes around the Sun an elliptic orbit, the distance which separates these two bodies differs constantly. About the 1st of January this distance is the shortest possible; the Earth is then at its perihelion, and the solar disc appears of its largest dimensions, about 1955½ seconds. At the aphelion, on the contrary (about the 1st of July), this distance is the greatest and the Sun's apparent diameter the smallest possible; it measures then only 1891 seconds. Lastly, its mean dimension is represented by $32' \, 3''{\cdot}64$ or 1923½ seconds, and occurs when the Earth is at its mean distance from the Sun, *i. e.* about the 1st April and 2nd or 3rd October. In this case the entire circumference of the horizon, or any other great circle of the celestial

sphere, would be filled by the juxtaposition of 673 discs similar to the solar disc, placed so as to be tangential to each other at the extremities of their horizontal diameter. 685 discs would be required at the aphelion, and 662 only at the period of perihelion.

At sunrise and sunset the Sun appears much larger than when it has risen to a certain height in the sky: the more it approaches to the zenith the smaller it appears. This is the case with all celestial bodies; the Moon and the various constellations appear near the horizon of an unusually large form. As I have given in my work on the Moon ('La Lune,' p. 27) the explanations which have been proposed by various observers to account for this curious illusion, I shall not refer again to them here.*

The variations of the apparent diameter of the Sun at different periods of the year concern us particularly, for, the intrinsic intensity of its light and heat remaining the same when the distance increases, it fol-

* [Many explanations have been proposed. It is a curious fact, but well known to astronomers, that the apparent diameter of the Sun or Moon at the horizon is precisely that which it shows at the zenith; if there be a slight difference, the disc at the horizon is *rather smaller* than when seen at the zenith, as we can assure ourselves by micrometric observation. We have often noticed, moreover, that the illusion disappears entirely when the disc at the horizon is observed through a tube of paper—a roll of music, for instance. It appears, therefore, to be an optical illusion owed to contrast.—P

lows that the amount of light and heat received by the surface of the Earth varies with the apparent superficies of the disc. An easy calculation shows that this variation is represented by the numbers 10,335—10,000—and 9,663. Hence, about the 1st January the Earth receives from the Sun more light and heat than on the 1st April or 1st October by 335-10,000ths; the reverse occurs about 1st July. This appears somewhat in contradiction with the fact of variation of heat which constitutes the different seasons, since the period at which the Earth receives the most heat from the Sun coincides nearly with our coldest weather in the northern hemisphere, whilst that at which it receives the least corresponds to the hottest weather in the same hemisphere. To explain this apparent anomaly would lead us far into an astronomical and physical discussion of the seasons, and cause us to deviate too far from our subject. Not to do this, let us say a word about the apparent dimensions of the solar disc as seen from the surface of the other planets.

It is from the surface of Mercury, the planet which, as far as we know at present, is the nearest to the Sun, that the central orb would be seen of the largest dimensions, and from Neptune, the farthest away, that it would appear the smallest. To avoid quoting numbers, which the mind retains with difficulty, we have placed on the following page a figure (fig. 13) showing the comparative sizes of the solar disc as seen from the

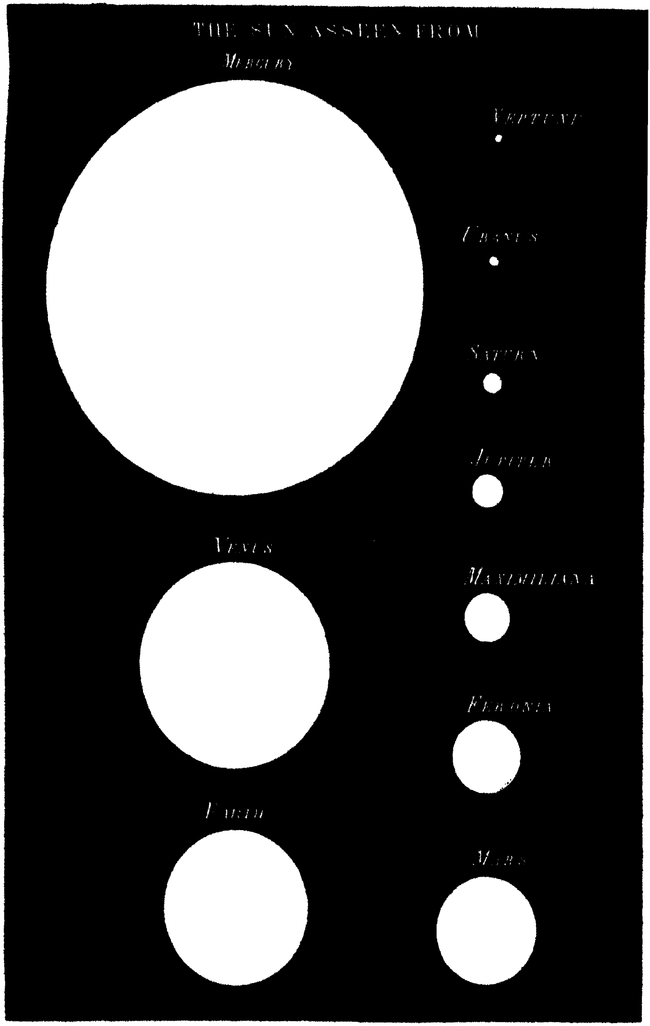


Fig. 13.—The Sun as seen from the different Planets.—Relative apparent Dimensions of its Disc at the Periods of their mean Distance.

various planets at their mean distances from the Sun. *It is well understood that as each orbit or curve, in which they revolve round the central orb, is of an elliptic form, the distances of each planet from the common focus varies in the course of their revolution,* as we have seen to be the case with the Earth; hence corresponding variations in the apparent diameter of the Sun, which is at its maximum at each perihelion, and at its minimum at each aphelion.

If we only take into account the apparent dimensions of the solar disc, in order to estimate the comparative intensities of the light and heat radiated from the Sun to each planet, an easy calculation gives us the following results, the light and heat received by our Earth being taken as unity:—

Mercury	6·673	Sylvia	0·082
Venus	1·910	Jupiter	0·037
Earth	1·000	Saturn	0·011
Mars	0·430	Uranus	0·003
Flora	0·206	Neptune	0·001

Thus, on the surface of the planet Mercury, the heat and light of the Sun have an intensity 6673 times greater than at the surface of Neptune; Mercury is lighted and heated nearly seven times as much as our Earth. Let us not forget, however, that reduced as the solar disc may appear at the confines of the planetary system (its apparent diameter is there only $= 1'4''$)

the brilliant orb shines at this enormous distance with the brightness of forty-four millions of stars of the first magnitude.

It is true that, in order to compare the calorific and luminous intensities of the Sun at the surface of the different planets, that is, on various parts of their soil, we should know something of the constitution of their atmospheres, and in what proportion waves of light and heat are absorbed in passing through these gaseous or vapoury envelopes. We have already seen the extent of the absorbing power of our Earth's atmosphere upon the solar rays, and how much their intensity is diminished at the horizon. It may be that Mercury, for instance, has an atmosphere of such density and composition that the soil of that planet does not directly receive more heat and light than the soil of the Earth does; on the other hand, it may possibly receive much more than is indicated by the foregoing table. We have, as yet, very few data concerning the atmospheres of planets, and with regard to the question now before us, we are well-nigh reduced to mere conjectures: we only mention the subject at all, in order that our readers may not draw erroneous inferences from imperfect or incomplete notions.

§ III.—DISTANCE OF THE SUN FROM THE EARTH.

What is the Parallax of a celestial Body?—How to measure an inaccessible Distance; horizontal Parallax —Measure of the Sun's Parallax; the Method used by Aristarchus of Samos; Oppositions of Mars and Venus; Passage of Venus.—The Sun's Distance deduced from the Velocity of Light and the Constant of Aberration.—Time that would be required to reach the Sun from the Earth; Light, Sound, a Cannon Ball, a Railway Train.

When you assert to a person unacquainted with the science of mathematics, that astronomers have been able to measure the distance of any celestial body from our Earth, your assertion is often received with a smile of incredulity. Unless, indeed, the person in question places implicit faith in what you say, and accepts the statement as a sort of scientific miracle, from having become accustomed to so many marvellous applications of science in modern times, and feeling inclined, to believe almost anything.

The present question is, nevertheless, one of surprising simplicity from a theoretical point of view, consequently easy to understand, but nevertheless very difficult and complicated in actual practice. In this case, and in many others, we shall have to adopt an opinion very different from that which is commonly received by the public at large. Let us endeavour to prove this with regard to the Sun's distance from the

Earth—a distance with which we must become acquainted before we can calculate its real size from its apparent dimensions. It is, moreover, one of the most important data in astronomical science: the Sun's distance is the unit of measure which is applied to all other distances either in the solar world or in the most distant regions of the heavens known as the stellar world, or the Universe.

In the first place we must define the meaning of a word which occurs frequently in the language of astronomers when they happen to speak of distance. This word is *parallax:* we hear them speak of the Moon's parallax, the Sun's parallax, the parallax of a star, &c. What is the parallax of a celestial body? It is this:—

In order to measure the distance that separates us from any point which we cannot approach—such is the case for the Sun, the Moon, and the stars—the observer first makes choice of a base. Suppose he is at a point A (Fig. 14) he traces upon the ground from this point A a straight line A C. This line is the basis of his operations, and all he requires is that it shall be straight and of known length, and that its two extremities, A and C, shall be of

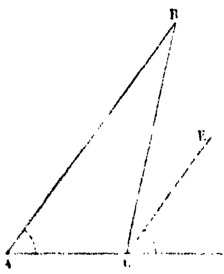


Fig. 14.—How to measure the distance of an inaccessible point.

easy access to him. At A he measures the angle B A C, which the visual ray of the distant object forms with the base line. At C he likewise measures the angle formed by the visual ray C B with the base. Now it is evident that these two determinations can be made simultaneously by two observers, one at A, and the other at C, both of whom look at the object B at the same instant.

It does not require much knowledge of mathematics to see that the triangle A C B is now known by one of its sides A C, the angle A and the angle C; and that to solve the question of distance we have only to construct a similar figure on paper. By then measuring with the same scale A C, either the line A B or the line B C, we shall know, without approaching in the slightest degree the point B, what is the exact distance which separates us from this point. This is a process which engineers and surveyors constantly resort to when they wish to measure a given distance over which they do not feel inclined to travel.

Let us return for a moment to the triangle A C B. Its three angles, like those of any other triangle, are, as every one knows, equal to 180°. Therefore, since the two angles A and C have been measured, their sum can be deducted from 180°, and what remains will be the value of the angle B. Now what is this angle B otherwise than the visual angle at which an ob-

server placed at B would see the base line A C? It is also, if we like, the angle which measures the apparent motion of the object B as the observer proceeds from A to C: it is this particular angle that astronomers call the *parallax* of the object B, whether the latter be the Moon, the Sun, or a planet, &c., whose distance from the Earth they wish to ascertain.

Fig. 15.—Horizontal parallax.

Let T (in Fig. 15) represent our Earth, and E the celestial body whose distance we wish to know. We require to find the value of E T, the distance from the centre of the Earth to the centre of the planet, Moon, or Sun. An observer placed at A on the line E T sees the Sun at the zenith, whilst a second observer, placed at B, measures the angle E B Z, which measures the distance of E from his zenith. This gives him the angle E B T. Moreover, the angle A T B is known: it is expressed by the difference of latitude between the two observers if they are on the same meridian. The radius of the Earth T B is likewise known; it forms the base of the triangle. A very simple calculation will, therefore, allow us to find the value of T E. As to the parallax, or the angle T E B, it is so much greater the farther B and A are separated, until one of the observers is at C where

the Sun would be seen by him at the horizon; that is why the parallax, in these circumstances, is called a *horizontal parallax.*

By means of special operations, which are more or less complicated according to circumstances, astronomers calculate this parallax for each celestial body, and by its means they obtain its distance from the Earth. Our readers will see that it might be accurately defined as the angle which, to an observer placed upon the celestial body, would be subtended by the Earth's radius.

It will now be easily perceived that the further the celestial body is removed from the Earth, the smaller will be this angle—its parallax—or the smaller would the radius of the Earth, as seen from the celestial body, appear. The truth of this is verified every day when we look at distant objects on the Earth's surface; the greater the distance that separates us from them the smaller they appear.

The older astronomers had endeavoured, like the moderns, to ascertain the Sun's distance, or, in other terms, to take its parallax. But this is a very delicate problem in actual practice, because the Sun's parallax forms a very small angle indeed; they tried to escape the difficulty by comparing the distance of the Sun with that of the Moon. The latter being much nearer to the Earth was approximately known, at least in the time of Hipparchus, a Grecian astronomer who lived

at Alexandria about 2000 years ago. Thus, Aristarchus of Samos, 260 years before the Christian era, remarked very truly that the centre of the Sun, the centre of the Moon, and the eye of an observer, form the three summits of a triangle L T S (Fig. 16) in which the angle L is a right-angle when the Moon is at a *quadrature*, that is to say, when the light and dark portions of the lunar disc are separated by a

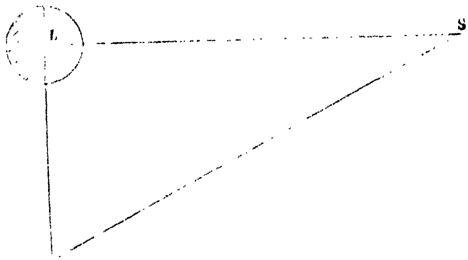


Fig. 16.—Determination of the Sun's distance by the method of Aristarchus of Samos.

perfectly straight line. Taking note, precisely, of this instant, either at the first or last quarter of the Moon, Aristarchus measured the angle L T S which is subtended by the distance of the Moon from the Sun, and deduced from it the ratio of the distance T S (the Sun's distance) to the distance T L (that of the Moon). But this method is not sufficiently precise, and the Sun's distance from the Earth, as found by Aristar-

chus, was very much too small. The same may be said of that employed by Hipparchus, and after him by Ptolemy, which consisted in measuring the diameter of the Earth's shadow in eclipses of the Moon. Up to the seventeenth century, things were in no better state with regard to this subject; the parallax of the Sun was set down as equal to three minutes, which would make its distance equal to 1146 times the Earth's radius, or only about 5,000,000 miles. We shall see that it is much greater than this.

Kepler, Riccioli, Hevelius, and Vendelinus, though they still made use of the method invented by Aristarchus, were provided with much better means of observation, and reduced the parallax of the Sun successively to two minutes, to twenty-eight seconds, and finally to fifteen seconds. The latter figure, nevertheless, is nearly twice as large as it should be.

However, Kepler made another kind of determination possible. This great genius discovered three astronomical laws, known among the moderns as *Kepler's laws*, which govern the motion of all the planets round the Sun, and one of which establishes a connexion between the duration of their revolutions, and their mean distance from the common focus. Therefore, before knowing these distances with absolute accuracy, before being able to express them by means of a well-determined unit, it was possible to calculate with precision their relative values. Thus,

the distance of the Earth from the Sun being considered as this unit of measure, that of Venus is 0·723, that of Mars 1·524. It resulted from this that if the distance of any one planet from the Sun were known with accuracy, that of all the others could be at once calculated without difficulty. Instead of seeking to determine directly the distance from the Earth to the Sun, or the solar parallax, it was sought to determine by observation and calculation the parallax of Mars and that of Venus at the periods when these planets are at their least distance from the Earth; that is when Mars is 'in opposition' and Venus 'in conjunction.'

By means of these observations on Mars during the last two centuries, the Sun's parallax was found to be 10″ by Cassini, 6″ by La Hire, 10″ by Maraldi, from 9 to 12 seconds by Pound and Bradley, and 10″·5 by Lacaille. We give these results to show how far observers still were from an accurate knowledge of the Sun's distance, even at this comparatively advanced period of learning.

A new method sprang up, however, and gave much more certain data. In 1761 and 1769 Venus passed over the Sun's disc, and the illustrious English astronomer, Halley, had announced beforehand how interesting these passages would prove in enabling astronomers to calculate the Sun's parallax. We could not, without entering into too many details, exhibit

here the method of observation recommended by Halley and practised by the astronomers of the eighteenth century. We must content ourselves with stating that when Venus comes into conjunction between the Sun and the Earth, this planet is considerably nearer to us than the Sun is. Its parallax is therefore greater than that of the Sun and consequently much easier to observe. Observers placed at very distant points on the Earth's surface will not see the planet pass over the Sun's disc (as a black spot) at the same points; for some of them the planet will appear at V (Fig. 17) and pass along the line B V A; for others it will be seen at V′, and will describe the cord D V′ C. As these cords are of unequal lengths the duration of the passage will not be the same for each observer. Now from the difference of these durations we can deduce the difference between the parallax of Venus and the Sun's parallax; and as we know the ratio of the one to the other, it is easy to calculate each of them.*

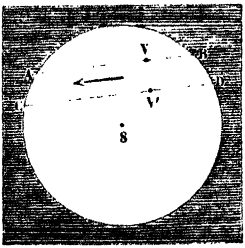


Fig. 17.—Sun's parallax determined by the passage of Venus.

When we say '*it is easy*' it must not be imagined

* For more ample details on this subject see the author's work 'The Heavens,' Book III. of which we now possess an English translation.

that the calculation can be made with one stroke of the pen: on the contrary, it is a very tedious and laborious calculation; what we mean is that that difficulty is reduced to mathematical calculation, the accuracy of which depends solely upon the degree of precision with which the observations have been made.

The astronomer Encke, by re-investigating the data obtained by the passages of Venus during the last century, found for the Sun's parallax the amount 8″·57 which has been generally adopted to within the last few years, and gave as the Sun's mean distance from the Earth about 24,000 times the equatorial radius of our planet. But philosophers are never satisfied. When a certain degree of precision has been attained they ask for still greater precision, and thus science progresses without intermission.

The parallax of the Sun as deduced, according to certain known methods, from the theory of the Moon's motion, and also from the perturbations of the planets, appeared to certain geometricians, among whom we must quote M. Le Verrier, to require a somewhat greater number than that found by Encke, a circumstance which would tend to reduce the Sun's distance from the Earth.

On the other hand, Léon Foucault having determined, by a new and very careful set of experiments, the velocity of light on the Earth's surface, and

having found it to be 298,000 kilometres (186,000 miles) per second, has enabled us to draw the following conclusions:—

A celestial phenomenon, called aberration, long known to astronomers, and measured with very great precision, is a consequence of the motion of light and the translatory motion of the Earth combined. Now a certain number which geometricians call the *constant of aberration* shows that the velocity of light through space is exactly 10,000 times the mean velocity of the Earth. If, therefore, these experiments of Léon Foucault are correct it follows that the Earth moves 29·8 kilometres (18·6 miles) per second. From this we can calculate the distance it travels in a year, that is, its orbit; and this orbit, once known, its mean radius, or, in other terms, the Earth's mean distance from the Sun, is deduced as a mathematical consequence.

In this manner a figure is obtained for the Sun's distance which corresponds to a parallax of 8″·86.

To recapitulate: the passages of Venus furnished Encke with the number 8″·57; celestial mechanics and certain observations of the planet Mars give 8″·95; the velocity of light 8″·86. There still exists, we see, a certain amount of uncertainty which, it is hoped, will be entirely dissipated by the observations of the coming passages of Venus over the Sun's disc in 1874 and 1882.

We shall certainly not be very far from truth if we adopt, for the present, the parallax 8″·9. By doubling this we get 17″·8 as the angle subtended by the diameter of the Earth as seen from the Sun: this angle is so small that, at such a distance, our planet would not appear anything more than a dim star somewhat similar to Saturn as seen by the naked eye. But let us return to the Sun's distance.

The parallax 8″·9 gives for the Sun's distance from the Earth 23,189 times the length of the equatorial radius of our globe, that is to say, about 147,910,000 kilometres (91,308,642 miles). In round numbers let us say 23,200 radii of the Earth, or 148 million kilometres (upwards of 91 millions of miles.)* This would represent the Sun's mean distance from the Earth, when the latter is in that part of its orbit which corresponds to the first days of April and the first days of October. The extreme distances differ from one another by 778 times the Earth's radius, or 5,000,000 kilometres (3,087,037 miles), so that in winter we are some three millions of miles nearer to the Sun than in summer.† To sum up we have then,—

* [Until recently 95 millions of miles has been generally adopted by astronomers.]

† [The inhabitants of the Antipodes, for instance the Australians, experience the reverse of this, being three millions of miles nearer to the Sun in summer.—P.]

Distance from the Sun to the Earth

	Equatorial Radii.	In Miles.
Aphelion . .	23,580	92,833,333
Mean . . .	23,190	91,308,642
Perihelion . .	22,800	89,771,604

We must not look upon these numbers as absolutely true, but they cannot be very far short of truth. It is essential here that we should have a sufficiently accurate notion of these distances as compared with those we are in the habit of measuring upon the Earth's surface, and so to realise the immense distance at which the Sun is placed from the planet that we inhabit. Further on we shall see that even this enormous distance vanishes to a mere point before the dimensions of the sidereal world, or that portion of the Universe which is accessible to our telescopes. A few familiar comparisons will render the first of these assertions tolerably evident to all.

In the first place, we will allude to light which propagates itself in a straight line with an uniform velocity of 298,000 kilometres (186,000 miles) per second. In coming from the Sun to the Earth it requires $496''\cdot35$, or $8^{m}\ 16^{s}\cdot35$ to pass over the 91 millions of miles. A cannon-ball weighing 24 pounds, shot from the gun with 12 pounds of powder, accomplishes 545 yards in the first second of time. If it kept up this velocity to the end of its journey it would require $9\frac{3}{4}$ years to reach the Sun.

If the space which is comprised between the Sun and the Earth were capable of transmitting sound with the uniform velocity of 370 yards per second—which is its velocity at 60° Fahr. in our atmosphere—it would require no less than $13\frac{3}{4}$ years. If an explosion occurred on the Sun it would then be about 14 years afterwards that we on the Earth should hear the noise of it.

Let us imagine a line of railway connecting our globe with the Sun, a train proceeding directly, without any stoppages, and at the uniform rate of 30 miles per hour, would arrive at the Sun in $337\frac{1}{2}$ years. By leaving the Earth on the first of January, 1869, we should arrive at the end of our journey towards the latter end of the year 2206!

§ 4. Real Dimensions of the Sun. Its Mass and its Density. Intensity of Gravitation at its Surface

For the Sun to appear to us in the form of a disc having so large an apparent diameter in spite of its enormous distance from us, it is evident that its real dimensions must be something prodigious. The solar globe—we shall see presently that the circular form of the disc is owing to the Sun's spherical figure—has indeed a diameter which is no less than 108 times as large as that of the Earth. This proportion of the

diameter of our planet to that of the Sun is rendered more evident thus: the solar parallax doubled gives the apparent diameter of our Earth as seen from the Sun, that is $17''\cdot8$, and the mean apparent diameter of the Sun as seen from the Earth being $32'\ 3''\cdot64$ or $1923''\cdot64$, it is only necessary to divide this by 17·8 to get very nearly the ratio of the two diameters; in making the exact trigonometrical calculation we obtain:—

$$D = 108{\cdot}135\ d.$$

If we pass now to the dimensions of the Sun expressed in miles, square miles, and cubic miles, we find: that the radius of the central orb of our system is about 426,000 miles; the circumference, or measure of one of its great circles, would be 2,672,222 miles, which is about 108 times the corresponding dimensions of our Earth. The surface of the Sun, including its luminous envelope, which so dazzles our eyes, is scarcely less than 12,000 times that of our globe, or in round numbers about 2,300,000,000,000 square miles; whilst its volume must be expressed by 323,000,000,000,000,000 cubic miles, or thereabouts.

Perhaps the best means of appreciating so vast a figure is to compare it with the volume of our Earth itself, which is about 260,000,000,000 cubic miles, we find nevertheless that the volume of the Sun is equivalent to 1,273,000 terrestrial globes. The Earth is by

no means the largest of the planets, since Jupiter, Saturn, Uranus, and Neptune, are respectively 1230, 685, 74, and 85 times as voluminous as our planet. But if all the planets known, together with their

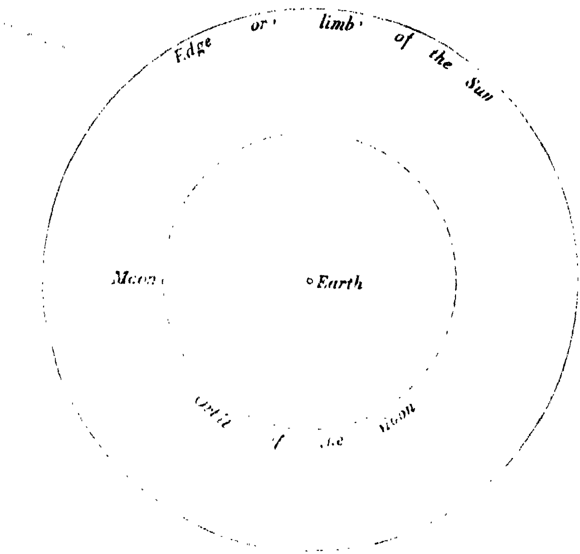


Fig. 18.—The circumference of the Solar globe compared to the orbit of the Moon.

satellites, were fused together into one globe, we should find that the volume of the Sun was still 600 times as great as this agglomerated mass. The Moon is separated from us by a distance equal to 64 times the Earth's radius, still, supposing that the centre of the

Sun coincided with that of our globe, not only would the entire lunar orbit be comprised in the vast solar sphere, but we should have to add to the width of this orbit 48 more radii of the Earth in order to reach the external surface of the central orb of our system. This is represented in Fig. 18.

The great importance of the Sun among the celestial bodies which gravitate around it, is better understood when they are all represented to scale, both as regards their respective sizes and their various distances. This is the object of figure 19. (See Frontispiece.) It is useful to exhibit these relative dimensions and distances by means of familiar figures and well-known measures.

Suppose that we represent the Sun as a sphere having a diameter of 4 inches, the Earth will then have to be represented as a minute grain less than 3-100ths of an inch in diameter, which we must place at a distance of $22\frac{1}{2}$ yards from the former, to place its real size and distance from the Sun in harmony one with the other. If the Earth be represented by an ordinary geographical globe, such as are used in schools, the diameter of which is about 1 foot, the solar globe to correspond must be placed at a distance of $2\frac{1}{4}$ miles, and be represented by a great sphere 35 yards in diameter. Jupiter, the largest of the planets, would likewise be represented by a globe $3\frac{1}{2}$ yards wide, which would have to be placed at 11 miles dis-

tance; Saturn would be a globe $3\frac{1}{4}$ yards wide placed at a distance of 20 miles.

What is the Weight of the Sun?—Some Notion of an Astronomer's Balance, or how Astronomers estimate the Weight of the heavenly Bodies.—How many Globes equal to our Earth would be required to counterpoise the Sun.—Weight of Bodies on the Surface of the Sun; its Mass compared to that of all the Planets put together.

Having spoken of the dimensions of the Sun, let us pass to another portion of our subject and speak of its mass, or the quantity of matter contained in this immense spherical volume. We will see how astronomy replies to this inquiry, which has even more right to excite astonishment and to give rise to incredulity than that concerning the distances of celestial bodies.

What is the mass of the Sun as compared with that of our terrestrial globe? If we could imagine a balance or pair of scales enormous enough to hold the Sun in one of its pans, how many Earths should we have to put into the other pan to counterpoise it?

This is not exactly the proper place to explain by what methods of deduction and observation, calculation and reasoning, astronomers have been able to solve this curious problem of celestial mechanics, and how they have been able to ascertain the weights of the Sun, the Earth, the Moon, the other planets and their satellites. We can only mention the principle, or

starting-point, and show how possible it is to solve the problem in question.

The principle is that of *universal gravitation*, the glory of formulating the laws of which belongs to Newton, and to which he appended the three laws of the immortal Kepler as natural consequences. Any two material points, said Newton, tend or gravitate towards each other with a force which is proportional to their masses, and which decreases as the square of their distances increases.

The Sun and planets, in one word, all the different bodies of the solar system, having a form which is very nearly spherical, each one acts upon the other as if its mass were concentrated to a single point placed at its centre. This is a second fact for which we are also indebted to the English geometrician.

A planet, such as the Earth, in circulating round the Sun, may be considered as subjected to two forces, the one called gravitation, by which it tends to approach the Sun; the other which, if it acted alone, would, on the contrary, remove the planet indefinitely from the Sun. The incessant combination of these two forces produces the elliptic movement (revolution) of which we have already spoken, and of which Kepler found the law which applies to all the planets. Putting aside, as a matter of very secondary consideration, the actions exercised by the other globes of the solar system, the following is the manner in which the re-

spective masses of the Sun and the Earth have been calculated.

What must be done to enable us to compare these two masses? We must find out what would be the force with which each of them would act upon a given *mass of matter in virtue of gravitation, provided that this mass were placed in each case at equal distances from the two others.* And as the said force can be measured by the space described in the first second of time, the problem may be put thus:—

What space would be passed over in the first second by a body falling by gravitation, that is, by the action of the mass of the Earth to a distance equal, say, to that of the Sun from the Earth? And what would be the amount of space described in the same time by a body falling through an equal distance towards the Sun by the influence of the solar mass?

Now, direct experiments have shown that in our latitudes a body which falls freely in a vacuum by the action of gravitation, that is, by the action of the mass of our globe supposed to be concentrated at its centre, travels over a space of 16 feet in the first second of time. The distance to the centre of the Earth from London is about 4000 miles. If the falling body be removed to the mean distance of the Sun, the space travelled over in the first second by this body as it falls towards the Earth would be reduced in the inverse ratio of the squares of the two distances 4000 miles,

and 91,308,642 miles; and so would the acquired velocity, which would be then represented by 0·000,000,006 of a foot.

We must now ascertain how a body, placed at the distance of the Earth from the Sun, falls to the latter by the action of its mass in the first second of time. The knowledge of the dimensions of the Earth's orbit, and of the mean velocity of the Earth in this orbit, allows us to make the required calculation, the details of which we will not give here, and we find 0·001 of a foot for the space passed through in the first second by a body falling towards the Sun, and the double of this number, 0·002 of a foot, for the velocity acquired in the same time.

The comparison of the masses of the Earth and Sun is the immediate consequence of these two results: the mass of the Sun is to that of the Earth as the number 0·002 is to 0·000,000,006. A simple division gives the ratio 333,333.

This number which we have arrived at by an elementary method, simply to show how the problem may be solved, and neglecting certain important elements of the question, is not the figure usually admitted. Astronomers have found the mass of the Sun to be equal to 325,000 times that of the Earth. The question before asked can, therefore, be answered thus:—

325,000 *Earths would weigh as much as the Sun.*

Now, every one knows that the specific gravity, or

density, of our globe has been found by different methods, and that the mean density of the Earth is fixed at 5·44, or thereabouts. The Earth weighs then 5·44 times as much as a similar volume of water. On multiplying this number by 325,000, we find the total weight of the Sun, which, reckoned in tons, gives us the frightful figure

2,154,106,580,000,000,000,000,000,000 tons.

The mass being known, we may divide it by the volume of the Sun, in order to find the specific gravity (or the density) of the matter of which it is composed, which is found to be 0·25136 (or nearly one-fourth) that of the Earth taken as unity. In other terms, taken in equal volumes, the weight of the matter which composes the Sun, is scarcely more than one-quarter of the weight of that which composes our globe. Compared to water the density of the Sun is 1·367. The most compact kind of coal has a specific gravity of 1·36, that of phosphorus is 1·77. Therefore the Sun weighs a little more than a globe of coal of the same dimensions, much less than a globe of phosphorus.

As the Sun is, after all, the body which preponderates over all the orbs which revolve in our system, it is interesting to compare it with each of them, at least with the principal planets, and to show at one glance the ratio of its mass, dimensions, density, &c., to theirs.

This is done in the following condensed table, where all these results are summarised:—

	Diameters: The Equatorial Diameter of the Earth = 1.	Volumes: The Volume of the Earth = 1.	Masses: The Earth's Mass being = 1.	Densities: That of the Earth = 1.	Weight at the Surface of the Earth = 1.
The Sun .	108·135	1,273,000	325,[illegible]00	0·251	27·366
Jupiter .	11·117	1,231	305	0·247	2·465
Saturn .	9·490	685	91	0·195	1·105
Neptune .	4·390	85	18	0·211	0·953
Uranus .	4·205	74	16	0·216	0·883
The Earth	1·000	1·000	1·000	1·000	1·000
Venus .	0·954	0·874	0·776	0·887	0·942
Mars .	0·536	0·154	0·111	0·720	0·382
Mercury .	0·373	0·052	0·076	1·420	0·540
The Moon	0·273	0·020	0·012	0·600	0·164

Many interesting considerations can be drawn from the simple inspection of this table.

On adding together the volumes of all the principal planets, we find that they give a total equal to 2077 times the volume of the Earth; adding to this the telescopic planets and the satellites of Jupiter, Saturn, Uranus, and Neptune, we should not increase the figure to more than 2080 at most, and this is contained 612 times in the number 1,273,000. The volume of the Sun, therefore, surpasses that of all the other planets together more than 600 times, as we stated previously.

If we consider the masses we find in like manner that their total is equal to 432 times that of our Earth, and that it is only about the 704th part of that of the Sun.

The four larger planets have each a specific gravity (density) which approaches very closely to that of the Sun, whilst the four planets of medium size, and the Moon, are formed of a much less dense substance; their mean density is 0·940, a figure which is nearly 4 times that which represents the density of the Sun.

There is a fifth column in our table where the intensity of gravitation at the surface of each planet, and at the Sun's surface, is indicated. This is what these figures mean:—At the surface of the Earth a body abandoned to itself in a vacuum, falls, at the end of one second of time, with an accelerated velocity which is equal to 32 feet. The space over which it has travelled up to that point is half as great, or 16 feet. It is this accelerated velocity which serves to measure the energy of terrestrial gravitation; it depends on the mass of the Earth, which mass is invariable; it depends also on the distance from the centre of the Earth at which the body begins to fall. The same element being calculated according to the known masses of the planets and their respective dimensions, gives us the numbers in the fifth column of our table, which permits us to calculate what would be the acce-

lerated velocity of a heavy body after falling for one second of time at the surface of each celestial orb.

At the Sun's surface this accelerated velocity is 27·366 times that of a body falling at the surface of our planet, or 872 feet ; the space travelled over in the first second would be the half or 436 feet.

Thus we see that bodies on the Sun's surface must weigh 27 times as much as upon the surface of the Earth, 29 times as much as upon Venus, more than 50 times as much as upon Mercury, but only 11 times as much as upon the surface of Jupiter. In other terms, if a one pound weight which upon the Earth causes the spring of a dynamometer to yield till it marks 1 lb. were carried to the surface of the Sun, it would there cause this spring to yield to the division which marks 27·366 lbs. The projectiles used by artillery, as M. Liais has shown, would, consequently, have a very small range on the Sun's surface. They would describe very considerable curves, and would fall to the ground at a few yards from the muzzle of the gun. It would require an immense charge of powder to send them to the distance to which they can easily be shot upon our Earth.

Upon the Earth the centrifugal force developed by the rotation of our globe diminishes the weight of bodies in a proportion which goes on increasing as we approach the equator. Upon the equator itself the total diminution is 1-289th. Upon the Sun the cen-

trifugal force at the equator is scarcely more than the 1-18,000th part of the body's weight. The Sun would have to turn upon its axis 133 times quicker to counterbalance the effect of gravitation at its surface, so that a body would be deprived of weight; whereas our Earth would only have to turn 17 times quicker to deprive all bodies on our globe of their weight. The very small amount of centrifugal force at the Sun's equator, compared to the intensity of gravitation at its surface, explains the absence, or, at least, the very small amount, of flattening observed on the solar globe, all the diameters of which, measured from the Earth, appear to be perfectly equal to each other.

CHAPTER IV.

ROTATION OF THE SUN.

§ I. DISCOVERY OF THE SUN'S ROTATION.

Fabricius, in 1611, discovers the Spots of the Sun and their apparent Motion.—Galileo determines the Duration of their visibility, and that of the Sun's Rotation.

THE solar globe rotates round one of its diameters, with an uniform motion in the space of about 25 days and a half.

The discovery of this fact, so important to the progress of astronomy, dates from the beginning of the seventeenth century, the period at which it was first given to man to observe the surface of the Sun with the newly-invented instrument called a telescope: it appears to be incontestably due to Johann Fabricius, to whom all the honour of it must be ascribed, as is proved by the paper which he published on the subject

in 1611. But both Giordano Bruno and Kepler* suspected that the Sun was endowed with a rotatory motion on its axis; and Galileo, who discovered the solar spots independently the same year that Fabricius first saw them, was not long in arriving at the same conclusion as the Dutch observer. The following are the circumstances in which this interesting discovery was made:—

One day, as Fabricius was observing the solar disc by means of a telescope, he noticed with surprise a blackish spot of considerable size, which he first took be a cloud, upon the surface of the Sun. On examining it attentively he found that he was mistaken as to its being a cloud; but as the Sun mounted higher in the heavens he was unable to continue his observation (for in those days the idea of using dark glasses for observing the Sun had not yet occurred), he was

* It is rather remarkable, says Humboldt in the third volume of his 'Cosmos,' that Giordano Bruno, who was burnt at the stake eight years before the invention of the telescope, and eleven before the discovery of the Sun's spots,[1] believed that the Sun rotated around its axis. In 1609 Kepler published his work, 'Astronomia nova, seu Physica Cœlestis,' in which he demonstrates, by his observations on Mars, the two first of his laws. In a passage of this work he explains the movements of the planets by the rotation of the Sun.

[[1] This distinguished man was burnt at Rome on the 17th February,

obliged to postpone his examination of the singular phenomenon until the following day. 'My father and myself,' he says, 'passed the remainder of the day and the whole night in a state of extreme impatience, and trying to account to ourselves what this *spot* could be. If it is in the Sun,' said I, 'we shall, no doubt, see it again; if it is not in the Sun, its motion will render it invisible to us. However, I saw it again early the next morning, with inconceivable pleasure; but it had changed its place a little, which circumstance increased our uncertainty about it; nevertheless, we determined to receive the Sun's rays passing through the small aperture of a camera oscura, upon a sheet of white paper, and we then saw this *spot* very well in the form of an elongated cloud. Bad weather prevented our continuing these observations for the next three days; at the end of that time we again saw the *spot*, which had advanced obliquely towards the west of the Sun's disc. We saw another, a smaller one, near the edge of the disc; in a few days this one reached the middle of the disc. Finally, a third made its appearance; the first disappeared soonest, and the others a few days afterwards. I was agitated alternately with hopes and fears lest I should not see them again; but ten days later the first of them reappeared at the east of the disc. I then understood that it had made a revolution [round the Sun], and since the commencement of the year I have convinced myself of

the truth of this notion; and I have shown these *spots* to other persons, who, like myself, are persuaded that it is so. Nevertheless I was troubled with a doubt which prevented me, first of all, writing upon this subject, and which made me regret the time I had lost in making these observations. I noticed that these *spots* did not always remain at the same distances from each other, that they changed both their forms and their velocities; but I reaped all the more pleasure when I perceived the reason of this. As it is probable, from these observations, that the *spots* are upon the body of the Sun itself, which is spherical and solid, they would of course appear smaller and endowed with slower motion as they approach the borders of the Sun. We invite the lovers of physical truths to profit by the sketch we here lay before them; they will, doubtless, suspect that the Sun has a turning motion, as Jordanus Bruno has asserted (in his 'Treatise on the Universe,' published in 1591), and latterly by Kepler in his book on the motions of Mars, for without this I do not know what we could make of these *spots*.'

As may be seen by this passage, quoted by Lalande, Fabricius had certainly observed the apparent motion of the black spots on the surface of the Sun, and had proposed, as a probable explanation of it, the rotatory motion (turning motion) of the solar globe. Galileo was still more precise and explicit; he fixed the time,

or period, during which a solar spot remains visible, which is about 14 days. He refuted the hypothesis of the Jesuit Scheiner, who believed the spots to be remote from the Sun and assimilated them to planets turning round the central orb and presenting their dark sides to us, as occurs with Venus and Mercury when they happen to pass across the Sun's disc.

Scheiner was convinced by the reasons which Galileo brought forward; he made a considerable number of observations himself, which he has consigned in a large folio work of 800 pages, published in 1630, with the title 'ROSA URSINA, *sive Sol, ex admirando facularum et macularum p*

The rotation of the Sun upon its axis was thus discovered about half a century sooner than that of the planets Venus, Mars, and Jupiter, and at the same time the old notion about the incorruptibility of the heavens or the stars, which had come down as a legacy from the ancients, was profoundly shaken. The Sun itself, that dazzling centre of light, that type of absolute purity, was found to have spots, and as we shall soon see, variable, movable spots, indicating incessant changes on the Sun's surface.

§ 2. Uniformity of the Motion of Sun-Spots.—Real Period of Rotation.

Progressive Motion of the Spots from the Western to the Eastern Edge of the Sun's Disc.—The Spots are upon the Surface of the Sun; their real Motion is uniform.—Direction of this Motion and Mean Period of the Rotation.

Without troubling ourselves at present about the nature of the Sun's spots, let us examine how the observation of one of them seems to determine the rotatory motion, its uniformity, and its period.

By means of an astronomical telescope, which reverses the objects seen through it,* let us observe a spot at the commencement of its course (at *a*, fig. 20), near the eastern border of the disc. It appears then like a thin line or stroke, generally much longer than it is wide. In the first few days it appears to travel slowly, but visibly approaches the centre; its velocity increases from day to day until it reaches the centre of

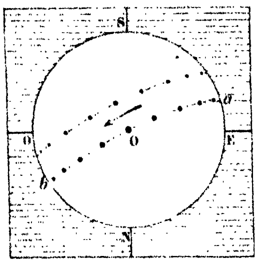


Fig. 20.—Apparent Motion of a Spot across the Disc of the Sun.

* In an astronomical refracting telescope the highest point of the solar disc N is seen at the bottom of the image, and the lowest point S at the top. In like manner the eastern edge, to an observer, is on the right of the disc at E, and the western

the disc itself, or, at least, the middle of its course (*o*, fig. 20). At this moment it has attained its maximum velocity, and from *o* to *b* its velocity decreases gradually as it formerly increased.

If two or more spots are visible at the same time, it is, of course, rare that they happen to be at the same periods of their motion, but, nevertheless, it is remarked that their courses are parallel, and similar to one another; sometimes straight, sometimes elliptic, according to the time of observation. Moreover, though so variable in form and dimensions, they are all seen with difficulty when near to the Sun's edge, where they appear, as we have just said, very narrow or elongated: the nearer they are to the centre of the disc the wider they appear to be.

However distant their courses may be from the centre of the disc, the same interval of time always elapses between the opposition of the spots at the eastern edge and their disappearance on the western border.

edge on the left at O, contrary to the positions in which these points are seen with the naked eye, or with a hand-glass.

It should also be remarked that the solar disc, carried along by diurnal motion from sunrise to sunset, takes successive positions which are such that the point which is the lowest at the moment the Sun rises above the horizon, ascends gradually until, at sunset, it is the highest point of the disc. This observation is necessary, in order to understand the apparent motion of the Sun's spots.

It often happens, however, that a spot, after disappearing on the western edge, reappears at the opposite side of the disc, and we then find that the period during which a spot is visible and that during which it is invisible, are very nearly exactly equal to each other, or a little less than fourteen days each.

All these facts point undeniably to a rotatory motion of the Sun itself; the spots are temporary accidents upon its surface, and the rotation enables us to examine the solar sphere all round.

They belong to the surface itself. If, indeed, they were produced by bodies moving at a certain distance around the Sun, like the planets, their apparent motion in front of the disc would be so much the more uniform the greater their distance from it: that is, in fact, what we observe during the passages of Mercury and Venus. Moreover, they would project black shadows on to the solar disc, but these shadows would preserve the same apparent dimensions near the edge as well as at the centre of the disc: there would be none of those changeable forms which we remark in the solar spots. Finally, the duration of their passage across the Sun would be much shorter than the interval during which they would be invisible, which would necessarily correspond to a much greater portion of their orbits.

It was once supposed, also, that the spots travelled over the Sun's surface by a proper motion. There is

in this notion some degree of truth, as we shall see presently, but in reality it is the entire mass of the Sun which revolves and carries the spots along with it. How is it possible that isolated black bodies independent of the mass of the Sun, and independent of each other, could describe their courses with so much regularity, and move in such similar parallel lines?

The variations in the velocity of a given spot, when followed in its entire course from the eastern to the western limb of the Sun across the centre, precisely demonstrates the uniformity of the Sun's rotation. Fabricius was weil aware of this, and we shall soon see how true it is.

A spot which appears to us to describe a straight line or an elliptic curve across the solar disc, describes in reality a circle on the surface of the Sun. If we saw in front the half-circumference of the visible course, the spot, as it travels over the equal segments A *a*, *a b*, *b c*, *c d*, *e f*, *f g*, B *g* (fig. 21), would appear endowed with its true velocity; and if its motion was uniform, its apparent velocity would be also uniform. But we see the course of the spot in perspective, sometimes as a right line A C B, sometimes as an elongated curve A D B. Near the edge the projection

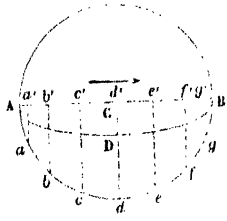


Fig. 21.—Apparent Progressive Motion of a Spot.—True Uniformity of this Moton.

of the arc A a is A a', which is considerably smaller; near the centre the arc $c\,d$ is projected in $c'\,d'$, nearly equal to it in size. Nevertheless, the two projections are described in the same interval of time by the spot. The latter appears, therefore, to be moving much more rapidly at the centre than it does near the edge of the disc. The ratio of the apparent velocities is easily calculated; and it is found to be exactly what geometry requires in the hypothesis of an uniform rotation. What occurs with a solar spot is then quite agreeable to the laws of perspective when we consider a sphere endowed with a rotatory motion around an axis terminating in two poles, the direction of which is invariable.

The fact is, therefore, beyond all doubt. The Sun turns upon itself, and the direction of the rotation is from right to left for an observer whose feet are upon the plane of its equator, and whose face is turned towards the northern hemisphere of the Sun. This is also the direction of the rotatory and translatory motions of the Earth, and of all the other planets; it is characterised by saying that they all turn from west to east.*

* When looking at the Sun the observer's face is turned towards his southern horizon, and, consequently, the rotation appears to him to be *from* the edge of the disc on the eastern side *towards* the western edge. This is the direction indicated by the arrows in the figures 21, 22, and 23.

The apparent period of a spot's motion is the interval which elapses, for instance, between the moment at which the spot passes the centre of the disc and the moment that it returns to the same point, for an observer upon the Earth. We shall see presently that this interval varies according to the latitudes of the various spots calculated from the Sun's equator. This explains certain discrepancies in the numbers found by astronomers who have determined this motion at various periods. Cassini gave the period of apparent rotation as $27^d\ 12^h\ 20^m$; Lalande, as $27^d\ 7^h\ 37^m\ 27^s$; Laugier, as $27^d\ 4^h$ on the average.

But the real period of rotation is shorter than the apparent period, and the cause of this difference is found in the translatory motion of the Earth round the Sun. In fact, if we suppose, for a moment, that the Earth is fixed, the time which a given spot would take, independently of any proper motion it may have, to return again to the centre of the disc, would, of course, be exactly that which the Sun takes to turn upon itself. If, on the contrary, the Earth ran through its entire orbit in the same interval that a spot takes to accomplish its rotation, the direction of both motions being the same, it is evident that the observer would accompany the spot, and that the latter would appear fixed upon the solar disc.

It is between these two extreme suppositions that the truth must be sought. Whilst the Sun performs

one entire rotation the Earth advances in its orbit in the same direction as the Sun turns. The spot which we supposed at the centre of the disc, when the observation was begun, comes back again to the same position on the surface of the Sun, but this position is no longer the centre of the disc; it is to the west of this centre; a certain interval of time is requisite for it to appear again at the apparent centre of the disc, during which the Earth itself advances still more along its orbit; but it is not difficult to deduce the period of real rotation from that of the apparent rotatory motion.

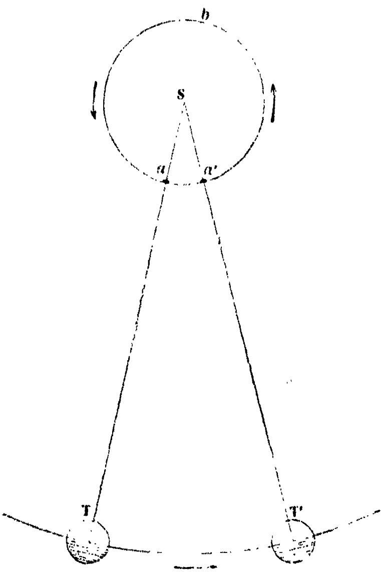


Fig. 22.— Difference between the interval of the Apparent and the real rotation of a Solar Spot.

Let a (fig. 22) represent a spot seen in the centre of the disc by an observer placed on the Earth at T. In a little more than 27 days the spot will have described an entire circumference $a\,b\,a$, *plus* an arc $a\,a'$, and it appears again to occupy the centre

of the disc for the observer who is now at T′. The whole question resolves itself into ascertaining how many degrees, minutes, and seconds, are contained in this arc $a\,a'$. Now this arc has the same angular value as the arc of the terrestrial orbit represented by T T′, which is nothing more than the course made by the Earth during one rotation of the Sun on its axis. Thus the spot is seen to describe an entire circumference *plus* a certain number of degrees equal to the extent of the said course travelled over by the Earth, which is well known.

A very simple calculation shows that the real duration of the Sun's rotation is about *two days* less than its apparent period. A spot which takes $27^d\ 4^h$ to come back again to the centre of the disc gives for the real period of the Sun's rotation $25^d{\cdot}34$, or $25^d\ 8^h$.

§ 3. Elements of the Rotatory Motion.—Poles and Equator of the Sun.

Courses of the Spots; at what Periods of the Year they appear to be in straight lines.—Nodes of the Sun's Equator.

Astronomers possess certain exact methods for determining the successive positions of a solar spot, the position of the axis of rotation, and, consequently, that of the poles and equator of the Sun.

If the axis were perpendicular to the plane of the ecliptic, or the Earth's orbit, the plane of the Sun's

equator would coincide with the ecliptic, and we should always see the spots travelling in straight lines across the disc, parallel to the ecliptic itself. But observation proves that this is not the case, for the courses of the spots vary with the period of the year,

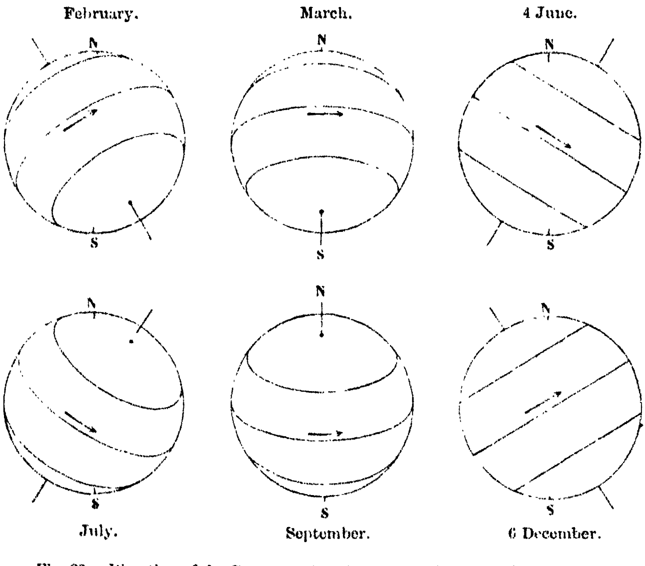


Fig. 23 — Direction of the Courses of Sun Spots at various periods of the year.

and appear sometimes as curves, the convexity of which is above, sometimes with the convexity below, or as straight lines, which are *not* parallel to the ecliptic.

According to Mr. Carrington, the solar equator is

inclined 7° 15′ on the plane of the Earth's orbit, so that the line of the poles forms with this plane an angle of 82° 45′. It results from this that the Earth in its annual course is sometimes above the plane of the Sun's equator; and then we see the spots describe ellipses, the concavity of which is turned towards the northern pole of the Sun, and sometimes below it, when we see the Sun's southern pole. In the latter case, the spots describe ellipses, the concavity of which is turned the opposite way. In two points of the Earth's orbit, diametrically opposed to each other, our globe is in the plane of the Sun's equator, and these points are called *nodes;* one is the ascending node, the other the descending node.* At this period the courses described by the spots appear to be straight lines, but inclined in contrary directions. This occurs about the 4th June, and between the 5th and 6th December, when the Earth passes the nodes of the solar equator and the spots carried along by the Sun's rotation appear to travel in straight lines across the disc. Therefore, from June to December the courses of the spots form concave lines towards the north pole of the Sun, and from December to June they appear concave towards the southern pole.

* According to Mr. Carrington, the longitude of the ascending node of the solar equator is 73° 40′ (1850). The Earth passes this point on the 4th of June.

§ 4. Variations in the Period of the Sun's Rotation in Different Latitudes.

Proper motions of Sun-spots—Difference between the period of their rotations according to their distance from the Sun's Equator—Observations made by Laugier, Carrington, and Spœrer.

If, as we have stated above, the rotation of the Sun as deduced from the observation of the spots on its disc were perfectly uniform, the calculation of its real period would always lead to the same figure, unless the spots were endowed with some degree of proper motion along the surface of the disc. Now attentive and prolonged study of these movements shows that things are not so absolutely regular as one might suppose. In the first place, the spots change their forms, their dimensions increase or diminish sometimes, which circumstance alone would suffice to introduce certain differences into the calculations of their positions. But it was early suspected that, besides their internal changes, the spots did not adhere firmly to a fixed and invariable position on the Sun's surface; that they had what is called a certain degree of proper motion, distinct from the general rotatory motion of the Sun itself which carries them always with it from west to east.

It results from a series of very minute observations

made by M. Laugier that not only do different spots give a notably different value for the Sun's rotation, but that the same spot observed at various periods of its movement offers similar discrepancies, though not to such a considerable extent. Twenty-nine spots thus observed gave as the mean period of a rotation $25^{d}\cdot34$; but the extreme periods observed oscillated between a maximum of $26^{d}\cdot23$ and a minimum of $25^{d}\cdot28$. The same spot gave as the exact value of the Sun's rotation numbers which varied to the extent of two to five hours.*

This evidently proved that the spots were endowed with a motion of their own, a fact which became still more certain when the variations of distance between two spots near to each other were measured. Thus it was that M. Laugier found for the velocity of the proper motion of a spot on the Sun's disc 111 metres (121 yards) per second.

A fact of very great importance which is in accordance with the preceding observations, was recently brought to light by the English Astronomer, Mr. Carrington. He concluded from a continuous series of observations of solar spots, extending over a period of $7\frac{1}{2}$ years, that the spots are not all endowed with the same angular velocity of rotation: this

[* This is a very considerable difference in astronomy, for at the present day observations can be made, according to M. Faye, to within 1-10th of a second.—P.]

velocity varies with the position of the spots with regard to the Sun's equator, *i.e.*, with their heliocentric latitude.*

In general, the nearer a spot is to the equator the more rapid is its rotation; the higher its latitude, the slower its motion. This variation, nevertheless, follows a regular and continuous law. We shall see, later, what consequences have been deduced from this fact with regard to the physical constitution of the Sun: in the meantime here are some results obtained by Mr. Carrington:†—

Rotation of the Sun at Different Latitudes.

Northern Latitude.			Period of the Rotation.		
	d		d	h	m
50°	27·445	or	27	10	41
30°	26·207	—	26	9	46
20°	25·714	—	25	17	8
15°	25·382	—	25	9	10
10°	25·145	—	25	3	29
5°	25·029	—	25	0	42
Equator 0°	24·913	—	24	2	11

* The German astronomer, Herr Spœrer, arrived independently at the same conclusion.

† The details of these observations are contained in a splendid work published in 1863 entitled "Observations of the Spots on the Sun, from Nov. 9, 1853, to March 24, 1861, made at Redhill by Richard Christopher Carrington." The Paris Academy of Sciences awarded its Lalande prize to this work in the year 1864.

Southern Latitude.			Period of the Rotation.		
	d		d	h	m
5°	24·971	or	24	23	18
10°	25·233	—	25	5	35
15°	25·573	—	25	13	31
20°	25·745	—	25	17	52
30°	26·535	—	26	12	50
45°	28·458	—	28	11	0

As a consequence of the rotatory motion of the Sun around one of its diameters the form of its globe must be that of an ellipsoid, flattened at the poles, or, in other terms, swollen at the equatorial regions: this is a necessary effect of the centrifugal force. We know that the Earth has a similar shape, and so have the planets Mars, Jupiter, and Saturn. Nevertheless, it is impossible to detect any appreciable difference in the diameter of the solar disc. The reason of this lies in the preponderance of gravitation over centrifugal force on the Sun, as we have already seen, the latter force being comparatively small with a rotatory motion so slow as that of the Sun.

We must not forget, however, when speaking of the slowness of this rotation, that angular velocity is meant. The real velocity of a point upon the Sun's surface is something very considerable, for it travels no less than 2200 yards per second; this velocity is really, then, about $4\frac{1}{3}$ times greater than that of a point upon the Earth's equator.

CHAPTER V.

The Sun in the Sidereal World.

§ 1. The Sun is a Star.

The Sun as seen from Neptune, from the limits of the planetary world—Its apparent size at the distance of the Fixed Stars, at the distance of Sirius—Chemical constitution of Stars similar to that of the Sun—The Sun is a Star of moderate size.

Let us imagine the Sun removed far away into the regions of space further and further from the Earth. What would it appear like to the inhabitants of our globe?

As it travelled farther and farther from us we should observe its apparent diameter diminish without noticing any diminution in the intrinsic intensity of its light. At the confines of the planetary system, at the distance of Neptune, its disc would be seen under an angle 30 times less than that we now observe, the mean value of which is 32′ 3″·6; there it would be reduced to 1′ 4″—

still a very appreciable diameter. As to the intensity of its heat and light, though reduced by a thousand times, it would still surpass to an enormous extent that of the most brilliant stars, for the light of the Sun illuminates the Earth with a force equal to that of twenty-two thousand millions of stars similar to the star *Alpha* Centauri, which is of the first magnitude (J. Herschel).

If it continued to travel still farther from us and penetrated beyond the limits of the planetary world which it warms and lights until it arrived at a distance comparable to that of the nearest fixed star, its apparent diameter would then be reduced to less than $0''\cdot01$, and the Sun would be almost imperceptible to us. The most perfect micrometer in the best of telescopes would not enable us to measure its dimensions. At a distance corresponding to a parallel of $1''$, which is equivalent to 206,000 times its actual distance from the Earth, the extinction of the Sun's light would be such that it would appear to us, at most, like a star of the first or second magnitude. Its brilliancy diminished according to the square of the distance would be reduced the 42,500,000,000th part of its actual value: this would make it about half as brilliant as the star *Alpha* Centauri. The brilliancy of Sirius is estimated to be about four times that of the latter; so that were our Sun transported to the distance of the nearest fixed stars, it would appear eight times less brilliant than Sirius.

What would it be if it were removed to the distance of Sirius itself, which is about six times as considerable as that which we have just mentioned? The extinction of its light would be of course 36 times greater, and in fact Sir John Herschel considers the intrinsic brilliancy of the star Sirius to be 225 times greater than that of the Sun.

Stellar photometry, or the comparative study of the luminous intensity of the stars, is still in a very imperfect state, and the numbers we have just given do not possess a very great degree of precision. They suffice, nevertheless, to render most evident the fact that our Sun in the sidereal world would only figure as a star— a star of ordinary size. On the other hand, the above considerations oblige us to consider the stars as independent sources of light. The enormous distance at which the nearest of them shine renders it impossible that they can be lighted up by borrowed or reflected light. They are Suns like our Sun, so that we can say, if we please, that the Sun is a star or that the stars are Suns.

These views, which throw so much light on the constitution of the universe, have been recently confirmed by comparing stellar light with that of our Sun. The method known to physicists as "spectral analysis" enables us to classify the various sources of light according to the nature of the spectrum which they give when this light is decomposed by means of a

prism. We shall see further on what is the signification of those dark lines which are visible in the solar spectrum; how they point to the presence of certain elementary bodies, metals or metalloids, which exist in the atmosphere of the Sun in the state of incandescent vapour.

Now when the spectra of the stars are studied in the same manner—about sixty of the more brilliant only have as yet been submitted to this kind of examination—we find a certain similarity of constitution existing among them all, and a certain resemblance to our Sun. The dark rays which are seen in their spectra indicate that starlight passes also through an absorbing layer of incandescent metallic vapour before issuing into the depths of space; but the chemical substances which characterize each of them varies from one to the other: sodium and magnesium exist in a great number; in others we find hydrogen, iron, bismuth, mercury, &c.

There exists doubtless in these distant worlds an infinite variety. Their real dimensions, the intrinsic brilliancy of their light, their colours, their chemical nature, and the number of substances of which they are composed, necessarily vary exceedingly. But one fact remains certain, namely, the great analogy which connects them with our solar world. Does there exist around each star, as around the Sun, a planetary system, with planets, satellites, and comets? This is indeed highly

probable, but their distance from us is too enormou to allow us to indulge in the hope of ever verifying such a conjecture by means of direct observation. It is quite certain that an observer placed upon any one of these stars which shine in the depths of the firmament, and looking in the direction of our world—Sun, planets, satellites, &c.—would see it like a single star, in the midst of a multitude of other stellar points.

§ 2. The Sun is a Star in the Milky Way.

What is the position of the Sun in the world of stars—The Milky Way; its form and constitution—The Sun is a Star in the Milky Way; its position in the Nebula, according to Herschel.

What is the position of the Sun in the sidereal universe? As it is one of the stars which comprise this universe, has it not some connection with any of the others, with regard to its situation and its movements? Does it not form part of some of those groups of stars which the telescope reveals here and there at infinite distances in the depths of space?

It is certain that a considerable number of stars are not completely isolated. Among those which appear single to the naked eye, there are thousands which show themselves as double or triple stars when seen with a telescope. And this is not often the mere effect of perspective, for in many of the double stars it

has been found that one moves or revolves round the other. Moreover, we know that a great number of those little celestial clouds, called *nebulæ*, are nothing else than an agglomeration of multitudes of stars whose enormous distance from us causes them to appear condensed into a comparatively small space. Is our Sun not one of the stars of such a group?

Since the time of William Herschel science has replied to this question in the affirmative. That great astronomer, that laborious and sagacious observer, demonstrated a fact which had already been hinted at by Kent, by Lambert, and by several other philosophers: namely, that the Sun forms part of that immense stellar agglomeration known as the Milky Way.

That great zone, indeed, is seen spread over the background of the heavens nearly in the form of a great circle of the starry sphere; if we put aside certain inequalities in its form, and certain inequalities in its width at various points of its periphery: it divides the sky into two portions, which are not absolutely of the same extent, the smallest half being that which contains the constellations Pisces and Cetus, that is, the constellations near the equinoxial point of spring.

Thus, already, it is evident from the general appearance presented by the Milky Way that it everywhere surrounds the spot which our world, and consequently the Sun, occupies in space.

To the naked eye, and to the eye armed with a

telescope, the Milky Way does not appear to possess in all its parts the same degree of brilliancy. The nebulous background of which it is composed presents various degrees of intensity, and as this appearance is owing to the agglomeration of multitudes of very small stars,* this condensation is very irregular in the various portions of the zone.

In order to study the comparative richness in stars of these portions, Herschel applied his well-known method of gauging the Milky Way, which consists in counting the number of stars visible in the field of his telescope as, carried along by the diurnal motion of the Earth, it passed successively over the various regions of the zone in question: he employed in this research more and more powerful instruments, having, as he observed, more and more power of penetrating into the depths of space. In this way he discovered that the extent of the Milky Way increased as the power of his instruments increased, and that in many points it is impossible to fathom it; its small breadth compared to its other dimensions shows that it is formed of a layer of Suns distributed in irregular heaps, and comprised between two planes nearly parallel one to the other, which gives to the entire figure the appearance of a

[* We know not on what authority the author makes use of the expression "very small stars"; it is certain that they appear very small to us, and he evidently alludes only to their apparent size.—P.]

flattened mill-stone, split into two portions throughout nearly one-half of its circumference.

It is about the centre of this gigantic agglomeration of stars, about the middle of its thickness, and near to the region where the separation of the zone into two layers or two principal blades occurs, that our little solar world exists—our little world, whose dimensions appeared at first so enormous, which was reduced, by a glance at the stellar world, to a star of the second or third magnitude, and which we now perceive to be a mere atom of luminous dust in the region of the Milky Way.

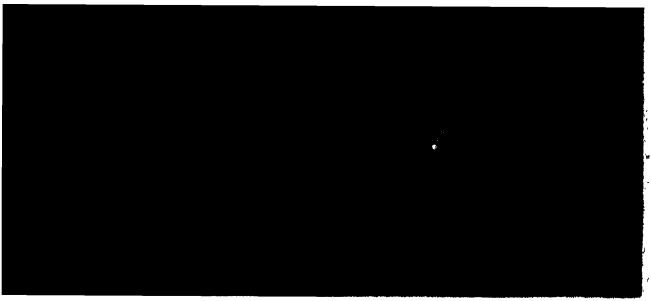


Fig. 24.—Position of the Sun in the Milky Way.

The position of the Sun in this zone accounts for the general aspect presented to us by the starry firmament, and shows besides that all the stars dispersed here and there, apparently so far from this great nebula, in reality form part of it.

Indeed, when from the point S where we are situated, we look in the direction of the length of the stellar stratum Sf (fig. 24), we meet with, so to speak, indefinite layers and clusters of stars which give to the Milky Way its density and its maximum of brilliancy. If, on the contrary, the eye looks in a direction less and less inclined such as Sa, the visual ray traverses strata rapidly decreasing in thickness, and consequently the density decreases with great rapidity. Finally, in the direction Sb, perpendicular to the thickness of the zone, the stars appear dispersed, as they really do in those parts of the sky which are most distant in appearance from this great nebulous zone. "Just as we see," says Sir John Herschel, in his *Outlines of Astronomy*, "a slight haze in the atmosphere thickening into a decided fog-bank near the horizon by the rapid increase of the mere length of the visual ray."

Fig. 24, which represents, according to William Herschel's views, a section of the Milky Way, perpendicular to its thickness, and along its greatest diameter which passes through the spot occupied by the Sun, renders the foregoing theory easy to realise. With its help we may account for the rapid decrease in the number of stars in those regions which, on both sides of the Milky Way, extend as far as the two poles of the great circle formed by this vast nebulous zone. These poles are situated, the north pole near the constellation Coma Berenices, the south pole in the con-

stellation of the Whale (Cetus). When from one of these points we advance progressively towards the Milky Way, the mean number of stars increases, at first rather slowly, then, in the vicinity of the galactic plane, with very great rapidity, so that the number is about thirty times greater in this plane than in the polar regions just mentioned.

Up to the present moment we have obtained but a general notion of the form of the Milky Way, and of the position which our Sun occupies in the midst of this immense nebula. To give a more complete idea of what is known regarding its structure, we must say a few words about its real dimensions.

On comparing the photometric brightness of stars of different magnitudes, with their probable distances, William Herschel arrived at the most astounding conclusions with regard to the dimensions of the Milky Way.

Stars which are visible to the naked eye include those comprised between the first and sixth magnitudes, as is well known. The illustrious astronomer of Slough supposed that, on an average, those of the sixth magnitude—*i. e.* the smallest that the naked eye can discern—are twelve times more distant than the stars of the first magnitude. Taking this as his starting-point, and calculating the penetrating power of his telescopes, he arrived at this result, namely, that he could observe in the depth of space stars which are

situated at a distance 2300 times greater than the mean distance of the stars of the first magnitude. Moreover, Herschel recognised that the visible extent of the Milky Way, in some regions, increased with the power of the instrument, but there even his great 40-feet telescope did not enable him to reach the limits of the vast nebula which he therefore declared to be *unfathomable.*

Now when we remember the enormous distance which separates us from the nearest star to our world —a distance which light itself takes years to travel over—we are led to the wonderful conclusion that the Milky Way, in the direction of the most distant regions accessible to our view, can only be completely traversed by a ray of light in an interval of time upwards of 10,000 years. Thus, when we place our eye to the ocular glass of the most powerful astronomical telescope, and perceive on the dark background of the sky faint, luminous points, we receive upon our optic nerve the impression of an undulatory vibration, which was set in motion at least 10,000 years ago by the incandescent matter of Suns, similar to our Sun, and forming part of the same sidereal group.

Calculating the thickness of the Milky Way from its apparent breadth, Herschel arrived at the conclusion that it was 80 times greater than the distance of stars of the first magnitude. Thus, the starry stratum greatly surpasses, even in this direction, the

limits of our sight. Whence it follows, as Struve has remarked, in his *Etudes d'Astronomie Stellaire*, and as we before observed, that "not only our Sun, but all the stars that we can see with the naked eye, are deeply plunged in the Milky Way, and form an integral portion of it."

§ 3.—Translatory Motion of the Sun in Space.

Opinion of Lalande on the probability of the Sun's Translatory Movement; connexion of this Motion with its Rotation.—Lambert's Views.—William Herschel solves the Problem; point towards which the Solar System Travels.—Universal Motion.

Thus we are not only made aware that the Sun is a star, but we can fix its position in the sidereal world: we find established with certainty that it forms part of the immense agglomeration of stars, star-clusters, and nebulæ, which is known as the Milky Way.

It remains for us to inquire whether our solar system is still, or endowed with motion in the midst of this infinite dust of stars.

We already know that the Sun rotates upon its axis. Now this fact alone would prove sufficient, had we no direct means of observation, to render it probable that the Sun had a translatory movement in space, which, we are going to show, is really an established fact. As early as 1776 Lalande suspected the

existence of such a movement, and showed its necessary and logical connexion with the rotatory motion. He thus expresses himself in his *Encyclopédie Méthodique* :—

'The rotation of the Sun indicates the existence of a translatory movement, or that the Sun travels in space, which will probably be recognised one of these days as a very important fact in Cosmology. Rotatory motion, considered as the physical effect of any cause, is produced by an impulsion communicated from without the centre; but any force applied to a given body, and causing it to turn on its axis, cannot fail to carry the body along, and it is impossible to conceive the one without the other. *It is, therefore, quite evident that the Sun must really move through absolute space;* but as it carries along with it the Earth, and all the other planets and comets which revolve round it, we cannot perceive this movement unless, after a lapse of centuries, it be observed that the Sun shall be found to have approached nearer to certain fixed stars than to others situated in an opposite direction. In such a case the apparent distances of the various stars from each other will be found to have increased in one direction, and to have diminished in another; and this will teach us in what direction the Solar system is travelling through space. But observations made on this head date from so short a period, and the distance of the stars is so great that it will be a long time

before we shall be able to determine the quantity of this translatory motion.'

Fontenelle, Bradley, Tobias Mayer, and Lambert, had also conceived that the Sun was endowed with a movement of translation, but without promulgating their notions in such precise language. 'Every fixed star,' says Lambert in his *Lettres Cosmologiques*, 'has its orbit traced out for it in the regions of space, and it describes this orbit carrying with it its hosts of planets and comets. If we could demonstrate that all bodies which turn upon themselves must necessarily travel along an orbit, it would be no longer possible to deny that our Sun travels along with the latter kind of motion, since it is found to possess the former. It appears that the mechanism of the world demands the connexion of these two kinds of motion, though we do not distinctly see the cause of it. It is, nevertheless, certain that the Sun travels . . . . . .' Speaking a little further on of the proper motion of fixed stars, he adds: 'As this apparent displacement of the fixed stars depends upon the movement of our Sun, as well as upon their own proper motion, we should have here, in all probability, a method of finding out towards what region of the heavens our Solar system is travelling. But what a length of time would have to elapse before we could know the period of the Sun's rotation! Would a platonic year—26,000 years—suffice? It may be that

during that space of time the Sun only passes through one sign of its zodiac!'

In all this we have merely theoretical conjectures; it was reserved for William Herschel to verify them somewhat by the aid of actual observation, and this was, doubtless, more difficult to do than to imagine the foregoing speculations, however sublime and ingenious they were for the period at which they were enunciated.

What was required to be done? To unravel and distinguish in the midst of the apparent or real motions which affect the stars, the general movement, that must be produced to an observer upon the Earth, and the supposed displacement of the Solar system in space, a movement totally unknown. The precession of the equinoxes, nutation, the annual course of the Earth round the Sun, the aberration of light, are so many causes which modify in one way or another the positions of the stars, once called 'fixed,' on the vault of the firmament. Each of them has, moreover—according to all probability—a proper motion, as we have actually proved to be the case for several of them, indicating a real translation through the regions of space. Let us imagine that we had determined the effects due to each of the above causes, and ascribed to them their true values, and then that we subtracted them from the total movement of celestial bodies, what would remain? Nothing at all, if the Sun were quite

immovable; but if, on the contrary, it is carried along through space, with all its hosts of planets, towards some region of the heavens, we should obtain a certain remainder; we should have for residue of all those apparent or real motions a certain amount of general motion. In the direction towards which the Sun advances along the stellar planes the stars would appear to become more distant from each other; their angular distances would increase as the Solar system approached nearer to them, whilst on the opposite side we should observe them to converge, the stars would group themselves closer together as we travelled further and further from them.

It is thus, in fact, that a traveller advancing from the centre of a vast plane towards one of its horizons, sees all the objects before him in the distance getting further and further from each other as he approaches them, whilst those he leaves behind him appear in like manner to close up to one another by a natural effect of perspective. At each side of him the trees appear to move in an opposite direction to that in which he travels. All these apparent motions, however various in direction, are intimately connected with the direction and rapidity of our traveller's course, so that if he did not know what road he was taking, the correlation of all these movements would enable him to find it out.

But though the problem from a theoretical point

of view appears so simple, it is otherwise when we come to solve it by direct observation; then, indeed, it becomes a very complicated and difficult one. With his usual boldness and perseverance, William Herschel grappled with it, and in 1783 he actually announced that it was solved, or at least roughly sketched. He concluded, from the careful examination of the proper motions of a small number of stars, that the Sun travels towards the star γ of the constellation Hercules, at that period in a point of the heavens corresponding to Right Ascension 257°, and North Declination 25°.

Fifty years later the distinguished Prussian Astronomer, Argelander, took up the question again with the aid of more numerous and more precise data, to determine the exact point of convergence. Then Otto Struve, Gauss, and Galloway, followed up the subject, and their researches confirmed those of Herschel and Argelander. The combined results of Struve and Argelander gave for the point in question for the year 1840,—

R. Ascen. . . . 259° 35′·1.
North Declin. . 34° 33′·6.

Struve succeeded, moreover, in determining the velocity of the translatory motion. Seen in front from a distance equal to the mean distance of one of the stars of first magnitude, the course described by the Sun in one year would have an angular value equal

to 0″·34 (34-100ths of a second), which is equivalent to 1623 times the mean radius of the Earth's orbit.

To recapitulate: 'The movement of the Solar system through space is directed towards a point of the celestial vault situated on the right line which joins the two stars of the third magnitude π and μ of Hercules, at one quarter of the apparent distance of these stars from each other, starting from π. The velocity of this movement is such that the Sun, with all the globes which depend upon it, advances in this

Fig. 25.—Point of the Heavens towards which the Sun travels in its translatory motion through space

direction at the rate of 1623 times the length of the radius of our orbit (150,000,000 miles), per annum.'

This is a velocity of about 412,000 miles per diem. or nearly 5 miles per second.

Thus we see that direct observation has once more legitimised the inductions of theory. The reality of this motion, by which the Solar system is carried along in the depths of space, is proved. It still remains to be known what the nature of this motion is—whether the Sun moves periodically around some unknown centre, if it forms part of any particular stellar system, some fragment of the great system of the Milky Way, or if it is the satellite of some other Sun. Perhaps its motion is merely the effect of the perturbations which it experiences from the stellar masses which surround it everywhere at unequal distances, and which are distributed irregularly in space.

In the first hypothesis—that of a periodic motion—the right line which represents the Sun's course towards Hercules is only a limited portion of the Solar orbit, and all that can at present be concluded from it is that the unknown centre around which it moves is at right angles to this line. In the course of several centuries it will perhaps be possible for astronomers to determine the curve of the orbit, by noticing a change in the direction of the Sun's path, and so acquire some idea of the distance of the orbit's focus. By studying the proper motions of the Sun and stars, as if they had a common focus, Argelander has examined the degree of probability presented by the hypothesis that the constellation Perseus would be the general centre of their gravitation. Mædler re-

gards Alcyone, the most brilliant of the Pleiades, as the central sun, around which our Sun oscillates,* and the Pleiades themselves as the group whose mass determines the motion of our solar system. These speculations, though they are but conjectures, are interesting, inasmuch as they act as points to which further inquiry may be advantageously directed.

The discovery of a proper motion with which our Sun is found to be endowed completes the analogies which bind it to all other known stars; for as sidereal astronomy progresses, the number of stars whose motion is perceptible increases, and we are forced to the conclusion that everything in the Universe is in motion, that nothing is still, or in absolute repose;† the immensity of the distances only give an apparent fixity to this multitude of celestial bodies which shine with sufficient brightness to cause their light to reach us. Nevertheless, years — thousands and millions of years—have elapsed since the vibrations of their surfaces occurred, which cause the impression of light to

* [The opinions of Astronomers generally are in favour of Baron Mædler's supposition, but much uncertainty must, of course, prevail with regard to this portion of our subject.—P.]

† See a paper on the Movements of Plants, by Dr. T. L. Phipson, in 'Macmillan's Magazine' for October 1864, in which the Author arrives at a similar conclusion in considering the organic world, and where he makes use of the sentence '*Motion, like Matter, is Universal.*'

be felt by us, and the motions which we at the present time detect with so much difficulty, *have been accomplished long ago.*

As to the course in which we travel through space, it is probable that we shall never know it with absolute accuracy; and the same may be said of all the globes of the Solar world. The Moon circulates round the Earth, but the ellipse which it describes is only, as we have seen it, a relative motion, for the Earth also revolves round the Sun; and even if we suppose the latter to be immovable, it is, nevertheless, true that our satellite describes a curve of various inflections, a species of cycloid which planetary perturbations render still more complicated. But since the Sun itself moves along also, the curve of the Lunar orbit is carried on with its motion, and its absolute figure in space is still more complicated. Who knows where this tangling of intricate curves, this combination of orbits, the last of which may be only apparent, really ends? The Sun exists in the Milky Way, which appears to be an agglomeration of world-systems, and it is possible that it forms part of one of these systems; but the collection of stars of which the latter is composed is influenced by the attractive forces of all the others, and the result is, doubtless, a general motion directed, perhaps, along the major axis of the great nebula. The Milky Way itself, with

all its millions of stars, what is it more in the visible Universe than an archipelago in the ocean?—but an archipelago in motion, that travels in infinite space, like all those other galaxies which the telescope has already revealed to us. When the thought of man plunges into these infinities he is bewildered, he loses all self-control, in spite of science, which opens to him these sublime glimpses of infinite space and time!

CHAPTER VI.

Physical and Chemical Constitution of the Sun.

§ 1. Opinions of the Ancients on the Sun's Nature.

Dimensions and Physical Nature of the Sun according to Ancient Opinions; Anaxagoras, Eudoxus of Cnidos.—First hypothesis suggested by the Discovery of Sun-spots.

The ancients had, and could only have, very imperfect and vague notions of the Sun's nature—of what is called now-a-days its physical nature: the doubt which at present, as we shall soon see, possesses the minds of the most learned astronomers, after so many years of research and interesting discoveries, sufficiently justifies the reproach of being ignorant, which one is tempted to offer to them. Without any means of precise observation, the ancients could only indulge in conjectures, of course very erroneous, on the dis-

tance and dimensions of the fiery globe which they looked upon as a satellite of the Earth. Thus, Anaxagoras professed that the Sun was not much larger than Peloponnesus. A century later, Eudoxus of Cnidos believed that the Sun's diameter was about nine times greater than that of the Moon—an appreciation that would have been less removed from truth if the Grecian astronomer had possessed better notions of the Moon's size than he possessed of the Sun's. If we must believe Cleomedes, who, like the Pythagoreans, looked upon the Sun as being steadily fixed in the centre of the world, the Epicurean philosophers of his century (that of Augustus) attributed to the central orb no greater dimensions than those which it appears to have to the naked eye—a circumstance which evidences an ignorance of the principles of geometry somewhat surprising for a period three centuries after that in which Archimedes lived.

However, as long as the true distance of the Sun remained unknown, it was impossible to do otherwise than speculate as to its size. *A fortiori* was it so as regards its physical nature. The epithets, *lucerna mundi*, *omnia intuens*, *visibilis Deus*, and *mens, rector mundi*, are evidence of admiration or religious adoration, not of astronomical opinion. The notion, according to which the Sun was a pure fire, the principle of heat and light, was naturally connected very intimately with that of the incorruptibility of the heavens, and of

all the stars which appeared fixed upon the various spheres imagined by the ancient observers and theosophists. Thus when Anaxagoras was bold enough to profess that the Sun was a mass of incandescent matter, he was accused of impiety and banished; the influence of Pericles, his disciple and friend, alone saved his life.

Do not let us be astonished, however, at these errors of a time far distant, when twenty-four centuries later—three centuries after the inauguration of the experimental system of observation, so many false notions and erroneous opinions are spread among the immense majority of people; nor must we be surprised at the persecutions which innovators have suffered, for even at the present day it is far from prudent to utter one's real thoughts, if they happen to be somewhat contrary to the opinions generally adopted on subjects connected with science and philosophy. Rather let us feel surprised to find hypotheses enunciated in the form of mere conjectures which a very advanced state of science could alone demonstrate the truth of.

The immobility of the Sun in the centre of the planetary world is one of these hypotheses to which we allude: it was imagined by the school of Pythagoras. Five centuries before the commencement of our era, Archelaus, a disciple of Anaxagoras, professed that the Sun was a star which surpassed all the others in magnitude. Heraclitus, who believed in the rotation of the

Earth, and some other philosophers of the Alexandrian school, taught, according to Plutarch, that every star was a world existing in the depths of the heavens, surrounded, like ours, by an Earth and planets. These philosophers anticipated Kepler himself, who, in his bold hypotheses on the constitution of the Universe, more than once outstripped the limits of observation and rigorous demonstration. In his 'Epitome,' Kepler actually says:—

'It is quite possible that the Sun may be nothing more than a fixed star, more brilliant to us than the others simply from its proximity, and that the other stars are really suns surrounded by planetary worlds.'*

Now we have seen above how modern astronomy has completely succeeded in assimilating the Sun to the stars, or in showing that the stars are suns, if that expression be preferred, having points of resemblance to our Sun, and certain analogies which permit us to consider them as orbs of the same nature.

The invention of the telescope, the discovery of the solar spots at the commencement of the seventeenth century, caused the problem of the physical nature of the Sun to pass suddenly from the ranks of pure or imaginative hypotheses to that of scientific hypotheses, that is, conjecture based upon scientific data and put forward with a view to explain them.

Before we enter into details upon the various

* Arago, 'Astronomie Populaire,' vol. ii. p. 162.

theories proposed to account for the Sun's physical nature we will quote a singular opinion, the production of which proves that scientific facts do not always suffice to prevent some people's imagination from rushing into the region of the absurd. The opinion in question was emitted at the end of the eighteenth century, and it would not be difficult to hunt up several others more or less similar, and dating even from more recent times. We borrow the fact from an English journal, 'The Reader,' in which we find it stated that, 'Of all the curious opinions imagined to explain the nature of the Sun, the most extravagant is doubtless that which is contained in "a Treatise on the sublime science of Heliography, demonstrating with satisfactory evidence that the great luminous sphere called the Sun is simply a mass of ice," published at London in 1798. "The Sun is a cold body," says the author, one Charles Palmer, "since temperature decreases as we approach it. Besides which, a convex lens of glass possesses the property of collecting together all the rays which fall upon it, to a focus; a lens of ice produces the same effect." For this reason the author [evidently insane] believes that the Sun is an immense convex lens of ice which receives the rays of heat and light emanating from the Almighty Himself and collects them to a focus on the Earth.'

§ 2. On the Surface of the Solar Globe.

Sun-spots; their general aspect—Nucleus and penumbra—Brilliant spots or faculæ—Forms and dimensions of the spots—Spots visible to the naked eye.

Copernicus and Kepler, by placing the geometry of the heavens upon a firm foundation, opened a new field of inquiry with regard to the movements of celestial bodies; they laid the basis of celestial mechanics, of which Huygens, Galileo, and Newton, were the founders. Mathematical astronomy then saw the light.

There remained, however, another branch of science which ancient observers had little notion of, and which could, in fact, only arise after the discovery of a new and powerful method of exploring the heavens. It is that branch of astronomy which relates to the intimate nature of celestial bodies, which has for its object to study particularly their forms, their dimensions, the details visible on their surfaces, in a word, their physical constitution. The application of optical laws to the construction of telescopes was the starting-point of this new branch of astronomy.

'To the century of great discoveries accomplished on the surface of our planet,' says Humboldt, 'immediately succeeds the taking possession, by the telescope, of a considerable portion of the celestial regions. The

application of an instrument which has the power of penetrating space, I might almost say the creation of a new organ of sense, evokes a whole world of new ideas.'

This was in fact what happened when Fabricius, Galileo, and Scheiner turned this new and marvellous instrument towards the solar disc. Although, at this period the power of the telescope was very slight, it revealed for the first time the existence of spots on the Sun, and at once suggested those hypotheses and conjectures which alone are fertile, namely, those based upon the results of actual observation.

The first telescopes used by Galileo magnified from 4 to 7 times only: the most powerful of them, one which he constructed himself, magnified only to the extent of 32 diameters. The surface of the solar disc was thus amplified successively, however, from 16 to 1024 times. Unfortunately, no one thought of attaching a dark glass to the eye-glass of the instrument in order to diminish the brightness of the image, so that it was only possible, as we have seen above, to observe the Sun late in the evening or early in the morning, whilst it was near the horizon, or again, when it was more or less veiled by clouds and fogs. This was sufficient, however, to enable Galileo to observe not only the black spots, and their motion, and the modification of their forms, but also to distinguish on the Sun's surface certain portions which were evidently much more brilliant than the neighbouring parts of the

disc, those which are now called *faculæ.* As these spots, like the others, are carried along by the common

Fig. 26.—Spots on the Sun, according to the observations of Sir John Herschel.

movement of the disc from west to east, it was not possible to maintain that the black spots are inde-

pendent of the Sun, and the rotatory motion was thus demonstrated in a very evident manner.

Let us now proceed to describe in detail the spots

Fig. 27.—Spots on the Sun from drawings by Sir John Herschel.

of the Sun, as we see them by the aid of the most powerful of modern telescopes.

First of all, we distinguish in a solar spot two tints,

very decidedly different, as may be seen by a glance at figs. 26 and 27.

One of these tints consists of one or more nuclei, which appear black when compared to the general brightness of the disc; the other is a grey tint surrounding the nucleus or several nuclei, and rather im-

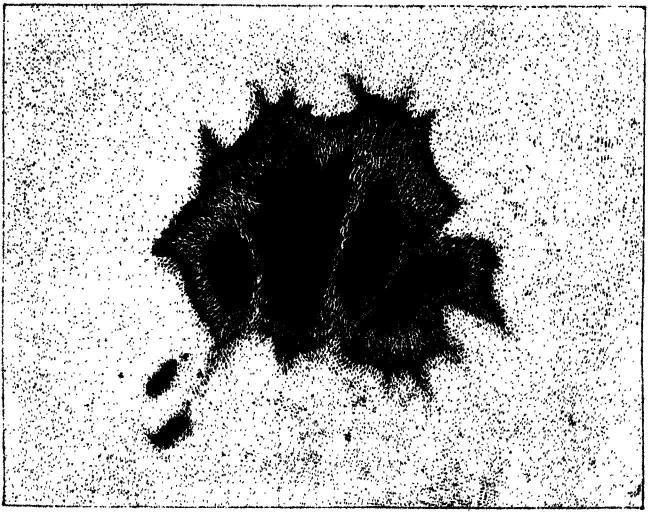


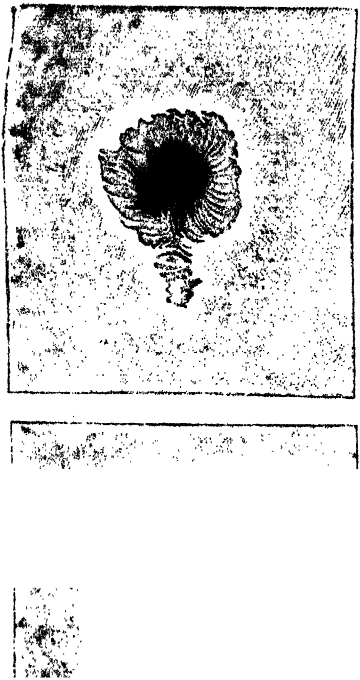
Fig. 28.—A Sun-spot, according to J. Nasmyth; Luminous Bridges.

properly called the *penumbra.* Sometimes, but not often, black spots or nuclei are seen deprived of a penumbra, and a penumbra is sometimes seen without a nucleus.

When minutely examined, the nuclei are far from

possessing the same tint in every part, though their periphery is generally very clearly defined.

On the dark background certain hollow portions are noticed, cavities of darker tint than the background; such a structure is seen in the figures 33, 35, and 36. The same remark holds good for the penumbra. It is those portions of their periphery in contact with the brilliant surface of the disc that are of the darkest grey tint, whether it be an effect of contrast or a reality, the difference of tint is, nevertheless, very marked (fig. 28). Besides, the penumbræ are very often striped with lines descending from their external border to the nucleus, sometimes as straight lines, sometimes curved, but generally perpendicular to



the Stripes of the Penumbra.

the edges of the penumbra and nucleus (fig. 29). They appear like the beds of a multitude of streams that have furrowed the slopes represented by the penumbra, and are precipitating themselves into the dark gulf of the nucleus; this, however, is only an idea evoked by the aspect of these phenomena, and in no way intended to anticipate the conjectures which we shall have to examine presently.

The same penumbra often envelopes several nuclei (also called *umbræ*), as we have already seen. But the latter are sometimes separated one from the other by narrow fragments of grey or brilliant matter; it appears, then, as if a nucleus (or umbra) was divided into several pieces by these thin fibres which Herschel has called 'luminous bridges.' The figs. 26, 27, and 28, show several specimens of this peculiar structure.

The forms of the spots, as may be seen by the numerous drawings which are here given from most authentic sources, are extremely varied. But whatever their forms may be, it is rare that a certain similarity does not exist between the parts which immediately surround the nucleus and those of the enveloping penumbra, a likeness which points evidently to the fact that the one is produced by the same causes as the other. The nucleus is seldom round; generally, its outline forms a sort of polygon with inward angles, and the penumbra repeats this form.

The dimensions of the spots are not less varied

than their forms: some are very small, appearing like minute points, even when scrutinised with a strongly magnifying instrument; this is the kind of spot which is oftenest seen as a nucleus without a penumbra, or as a penumbra without a nucleus. Figures 26 and 27 furnish examples of the one and the other. Certain spots of enormous dimensions have been seen from time to time. 'About the middle of the year 1763,' says Lalande, 'I saw the largest and the blackest sun-spot which I ever witnessed. It was 1′, at least, in length,' that is, equal to the 1-32nd part of the Sun's diameter, or thereabouts. Arago mentions a spot of 167″, or nearly three times as long as Lalande's. Schrœter measured one whose surface was equal to a circle having a radius equal to that of the Earth, which is equivalent to four times the superficies of our globe: its mean diameter measured about 30,000 miles. In 1779 William Herschel saw a spot which was not less than 50,000 miles in diameter. Those shown in fig. 30, from a drawing by Capt. Davis, show what enormous dimensions sun-spots sometimes attain; the largest of them, which has, however, a double nucleus, was not less than 187,000 miles in its greatest length: its superficies, including the penumbra, was about 25,000,000,000 square miles. If these spots are, as we shall see further on, great rents in the luminous envelope of the Sun, of what an immense capacity those enormous gulfs, those gigantic abysses, must be;

our entire globe would appear, in their depths, no larger than a fragment of rock rolled into the crater of a volcano!

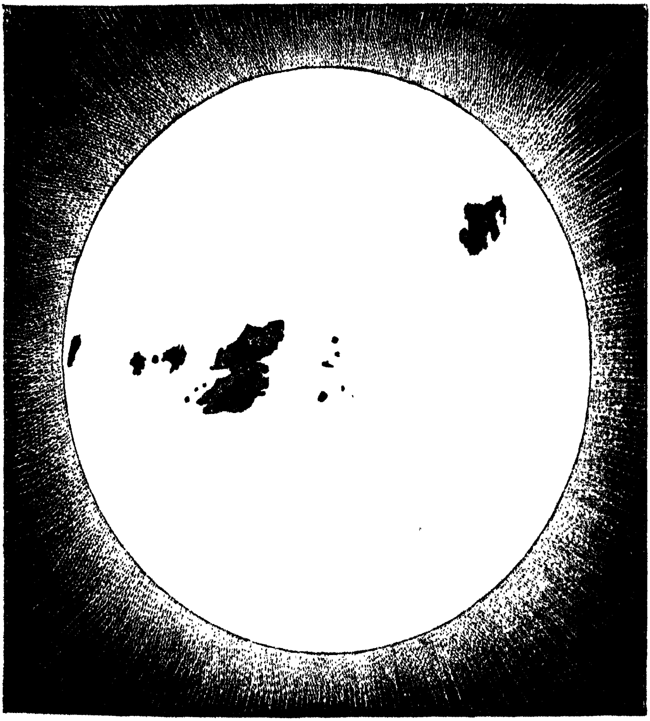


Fig. 30.—Large Sun-spots seen on the 30th August, 1839 by Capt. Davis.

With such dimensions as these the spots must sometimes be visible to the naked eye; and, indeed, the intense brilliancy of the solar disc alone prevents

our seeing them, but we have already shown how this obstacle may be easily done away with. It was, doubtless, to these phenomena that we must ascribe the pretended passage of Mercury across the solar disc in the year 807; the black spot, which was supposed to be the obscure disc of that planet, was visible for eight days. In the year 840, it was Venus that was supposed to be seen passing over the solar disc during a space of 91 days. Again, in 1096, it was asserted that 'signs were seen on the Sun,' *signa in Sole*. But in those days nothing was known of solar spots; after they were discovered these appearances gave rise to no more mistakes. Several observers have seen sun-spots with the naked eye; for instance, in August 1612, Galileo and some of his friends saw a spot of at least 1′ in diameter upon the solar disc at sunrise. It was seen for three successive days. The sight of a solar spot visible to the naked eye in 1779 determined William Herschel to turn his attention to the physical nature of the Sun. Herr Schwabe, who has devoted so many years to the investigation of sun-spots, has seen many that were large enough to be distinguished without the aid of a telescope. 'The principal spots appeared,' he says, 'in the years 1828, 1829, 1831, 1836, 1837, 1838, 1839, 1847, and 1848. I consider as large spots those which cover 50″ at least; it is at about this size that they become visible to persons with good eyes, without the aid of a telescope.'

On the 28th June, 1868, a very large spot on the solar disc was noticed by Mr. W. S. Gilman, of Palisades, Rockville Co., New York, who wrote of it as 'a spot visible to the naked eye;' and doubtless such would often be seen if people paid more attention to the subject.

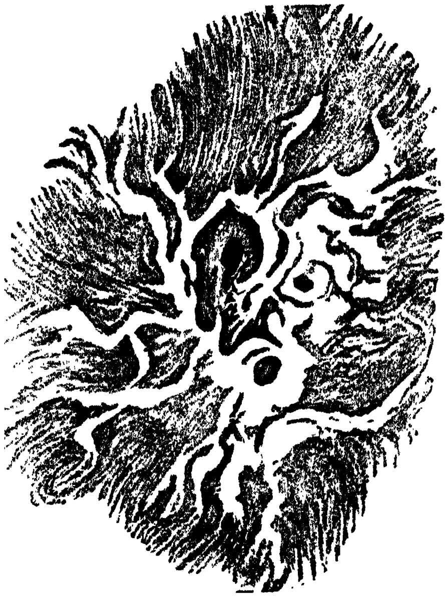


Fig. 31.—Faculæ in the neighbourhood of a Spot, from a Drawing by M. Chacornac.

The *faculæ*, or brilliant spots, were observed for the first time, as we have stated, by Galileo. Most frequently they accompany the spots, and are seen upon the external borders of the penumbra, so that it

might easily be imagined that they resulted from an effect of contrast between the black surface of the spot and the brilliancy of the surrounding portions of the disc; but this is not at all the case, for, besides the fact that faculæ do not always surround the penumbra, that certain spots are devoid of faculæ, the latter are sometimes seen to appear isolated on the disc, and their apparition usually denotes the approaching formation of a spot at that point.

Faculæ sometimes take the form of converging currents, terminating on various points of the periphery of a spot, like so many streams of brilliant matter. Fig. 31, for which I am indebted to M. Chacornac, furnishes a remarkable example of this state of things, very different from those represented in fig. 29.

Structure of the Photosphere; Pores or Granulations on the luminous Portions of the Disc.—'Willow-leaves,' their Disposition near a Spot and inside the Penumbra.

When the disc of the Sun is examined with a moderately powerful glass, all those regions which are not covered with spots—often the entire disc—appear of uniform whiteness, and gives us the idea of a perfectly smooth and flat surface. It is not so, however, when we observe the Sun by means of a very powerful telescope. In this case the brilliant surface appears covered with a multitude of luminous lines alternating with darker lines, and crossing each other in every

direction, so as to resemble, as several persons have remarked, the grain of an engraving. The figures 28, 32, and 33, will give some notion of this peculiar aspect presented by the solar disc. The more obscure portions to which we allude have been called *pores* or *lucules;* they are seen in every region of the disc, whilst the spots or faculæ only appear, as we shall see presently, in a certain limited zone on each side of the solar equator. We must except, however, the faculæ themselves, and the nuclei of the spots whose tints are nearly uniform; but those portions of the spots which, though of very variable tints, constitute the penumbra, when examined with a glass of sufficient power show a structure which is very similar to that of the granulated surface of the disc. The only difference appears to be that the pores in the penumbra are much larger, so that the less obscure portions of the penumbra appear to stand out separate from one another on the darker background. Their elongated forms caused them to receive from Mr. Nasmyth, a contemporary English astronomer, the name of 'willow-leaves.' Other observers have also noticed the existence of these luminous fragments, which have been compared by the late distinguished Mr. Dawes to slashed blades of straw, and by Mr. Stone to rice-grains; Mr. Huggins calls them simply *granulations.* The following is the manner in which the director of the Roman Observatory, Professor Secchi, describes the aspect

presented by the surface of the solar disc, away from the spots, on their borders, and in the interior of the penumbra (he observed with a great refracting telescope, by Merz, having a diagonal ocular glass):—

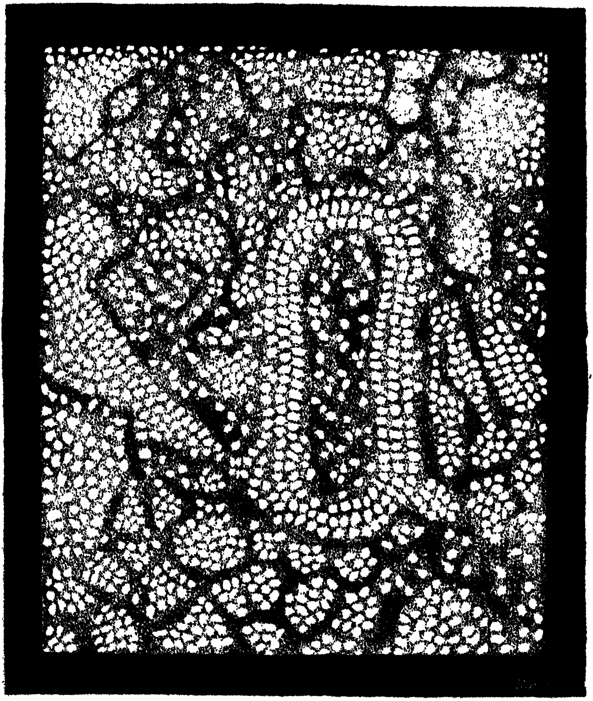


Fig. 32.—Pores or Granulations on the Surface of the Solar Disc, according to Mr. Huggins.

'The luminous background of the Sun is seen as a kind of tissue over which are dispersed a multitude of

white points, more or less elongated in form, and separated by a darker network, the points of intersection of this network appear like very minute black holes. The penumbra of the spots are more remarkable; there we see a great quantity of these elongated white bodies, which, arranged in lines, show themselves as a kind of filament, and these I have spoken of as *currents* in some of my previous observations. This configuration, however, is not constant, and the white bodies are not always separate in the penumbra. It is difficult to compare them with any known object. I would compare them to elongated masses of cotton, of every possible form, sometimes entangled one in another, at others dispersed or isolated. At times these masses are distinctly terminated and neatly truncated; sometimes again, they are spread out, and have no distinct termination. Their head is generally turned towards the centre of the nucleus. They are not unlike great strokes of colour laid on with a painting brush, very white near the head, and gradually less brilliant towards the tail. The general background on which they are dispersed, is formed by the faint light of the penumbra. This faint light is lengthened out in wide streaks, like the cirrhi clouds of our atmosphere, whilst the other portions might be compared to cumuli. The periphery of the entire spot is formed by the heads of all these white bodies, which give to it the aspect of a toothed wheel with rather prominent teeth.'

Fig. 33.—Groups of Spots observed and drawn by Mr. Nasmyth on the 5th June, 1864.

Figure 33 is the reproduction of an original drawing by Mr. Nasmyth, which this astronomer was kind enough to send us. In it may be seen all the details of a group of solar spots, the nuclei formed by the two superposed tints; one, completely black, like the depths of an abyss; the other, somewhat less dark, seems to point to a region less deep. All around is seen the penumbra, covered by, or rather entirely formed of, the so-called 'willow-leaves,' arranged in lines converging towards the nuclei; some of these lines, more brilliant than others, appear to be the continuation of the pores which cover the surrounding luminous surface. The latter appears to be formed of a closer weaving of the same tissue, a more intimate entangling of these singular elements, some of which, finding near the border of the gulf a space where they can move more freely, are carried into the interior, whilst others swim above in the form of luminous points. We shall see further on whether these phenomena can be satisfactorily explained by the theories professed at present with regard to the physical constitution of the Sun.

Such is, in a condensed form, the appearance presented to us by the Sun's disc when seen through a powerful telescope; a luminous surface of uniform brilliancy nearly, save the difference between the central region and the edge of the disc, to which we alluded before, and to this surface astronomers have given the

name of *photosphere*, whatever may be the different opinions held with regard to the physical nature of this envelope. This *photosphere* is covered with *pores*, or points, which are less brilliant than the spaces which separate them. Here and there a few spots; some formed of a black *nucleus* surrounded by a penumbra, others, shining with a light more brilliant than that of the photosphere, accompany the dark spots: they are the *faculæ*.

A few words now on the apparition, transformation, and disappearance of the spots, on their movements, on the regions in which they mostly show themselves, and, lastly, on their number and periodicity.

§ III. Apparition, Movements, and Transformations of Sun-Spots.

Their Number and Periodicity.—Connexion of this Periodicity with Temperature on the Earth, with the Movements of the Planets Jupiter and Venus, and with the Perturbations of the Magnetic Needle.

The spots on the Sun are not, like those observed on the Moon, permanent objects, fixed upon the disc; every one of them appears, is born, if we may so express ourselves, goes through a period of transformation, and then disappears. The duration of these successive phenomena is very variable.

The earliest observers of sun-spots were aware of

their changeable aspect. According to Fabricius, 'they change their form and their velocity.' Galileo observes, 'that they are not permanent, they condense themselves or divide, increase or are dissipated.' This fact was not one of great difficulty to put in evidence; for sometimes the solar disc was seen full of spots, and at others, perhaps none appeared during an entire rotation.

The apparition and successive changes of a sun-spot until the moment when it disappears completely, are phenomena which it is not always easy to follow up completely by observation, however assiduous. We can never see more than one hemisphere of the Sun at a time, and from the diurnal motion of the Earth upon its axis, the central orb is only visible during a portion of the four-and-twenty hours; moreover, a cloudy sky often prevents observation altogether. Thus it often happens that an astronomer, on pointing his instrument to the solar disc, sees a spot already formed where nothing was observed a little time before; or, he sees a spot, observed previously, so transformed in size and position, that it is scarcely recognisable again; or, finally, such a spot is found to have entirely vanished, either it has disappeared altogether, or the rotation of the solar disc has carried it out of sight.

We have already stated that *faculæ* are most frequently seen in the neighbourhood and on the borders of a spot. There exists, however, a more intimate

connection between them, as Schwabe, one of the most diligent of modern observers, truly remarks:—'There can be no doubt,' he says, 'that there exists an intimate connection between the spots and the formation of faculæ. Frequently I observe faculæ or luculæ at a point where a spot has disappeared, or new spots are seen to develope themselves in the faculæ.'

It does not appear probable that the largest spots are formed immediately with their greatest dimensions. According to Professor J. Chacornac, it is at those periods when the solar disc is most devoid of spots that a large number of small spots are seen to appear, first of all isolated and devoid of penumbra, then gradually becoming surrounded with the grey tint which characterises the latter, whilst the spot continues to increase in size. The nearest of the small black spots are connected together by portions of penumbra, finally they unite in a common penumbra, and the increasing nuclei blend together into one spot of large dimensions. It seems as if they were precipitated one into the other; and whatever hypothesis may be proposed as to the nature of sun-spots, there can be no doubt that the motions to which we allude here really exist. Among the earliest observers, Scheiner and Galileo were surprised at the rapidity of the changes presented by sun-spots. Derham, Wollaston, and William Herschel, have studied these changes very minutely; the latter has actually seen large spots formed by

the augmentation of a small black point which originally formed the nucleus, and he also has witnessed the disappearance of spots by a gradual shrinking of the nucleus, which often divided itself at these times into several distinct nuclei. 'In this case,' he says, 'the luminous matter of the Sun appears to spread over the cavity of the spot like a bridge.'

Arago, in his 'Popular Astronomy,' quotes a passage from Wollaston, where this observer speaks of the sudden division of a solar spot, and compares the phenomenon to what happens 'when we throw a sheet of ice upon the frozen surface of a pond, and see it break into a number of fragments, each of which slides away in all directions.' It appears evident to us that this comparison must not be accepted too literally, Wollaston only wished to convey a notion of the relative rapidity with which a sun-spot undergoes its transformations.

M. Laugier having measured the relative positions of two spots, concluded that one had receded from the other, supposing the latter to be fixed, with a velocity of 121 yards per second. According to the recent observations of M. Chacornac, small spots are precipitated into larger ones with a velocity which sometimes attains to 599½ yards per second. It is shortly after the apparition of a group of spots that the most extensive and rapid changes occur. This would explain the difference — more apparent than real — between the

spots which are seen to undergo rapid variations, and those whose permanence would indicate that these

4.—Spot observed by Dawes, th Oct. 1859.

Fig. 35.—Same Spot 29th Oct.

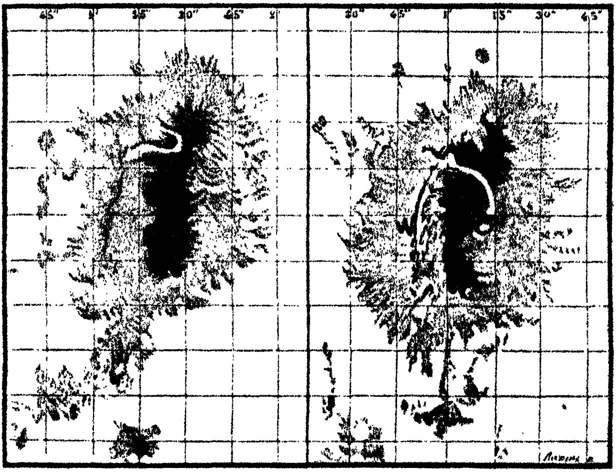
Fig. 36.—Same Spot, 31st October.

Fig. 37.—Same Spot, 2nd Nov.

variations were over at the time of observation. For instance, in July 1865, a great circular spot preserved

its size and form from the 7th to the 20th July, that is, during the whole time that it was observed, whilst a group which, at the latter date, occupied the middle of the solar disc, underwent rapid change in its form and dimensions.

The figures 34 to 41 represent spots whose varia-

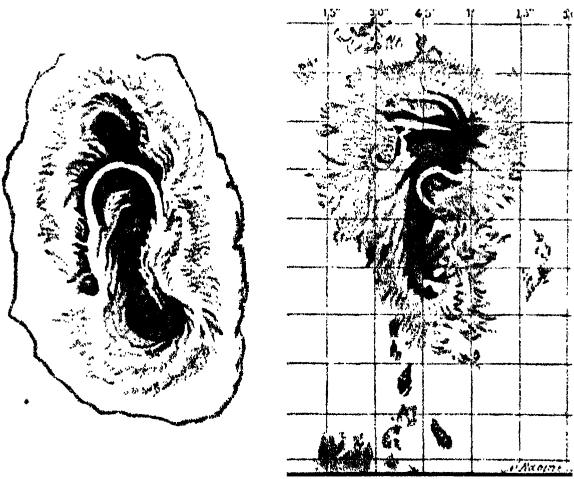


13th Oct. 1865, 8h 30m. 14th Oct., 9h.

Fig. 38 —Changes undergone by a Sun-spot, from Observations by Mr. Howlet.

tions have been observed at certain intervals. The first four show what happens to a solar spot observed every second day; in the two following the change undergone in the space of one day is depicted from the observations of an English astronomer, Mr. Howlet,

made in October 1865. Lastly, in figures 40 and 41, may be seen the transformations operated in several groups of sun-spots during the period of an entire rotation; there are, at the same time, plain indications of a considerable amount of proper motion, which has changed the respective positions of the groups, and



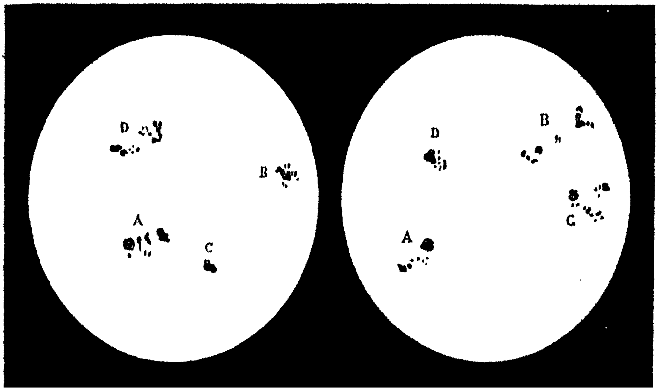
15th Oct., 10^h. 16th Oct., $8^h\ 30^m$.

Fig. 39.—Same Spot observed on the 15th and 16th Oct., 1865, by M. Chacornac (see fig. 38).

proof of the intimate transformations going on in each of them.

We see, then, that solar spots vary incessantly in form and position. The period during which they

exist on the Sun's surface is also very variable. Some—generally the smallest—merely appear and disappear, they last for a mere fraction only of the 25½ days in which the rotation of the Sun is accomplished. Others, on the contrary, remain visible during several successive rotations, most frequently during one or two rotations.



g. 40.—Transformations in groups of Spots in the interval of a rotation, according to Pastorff, 24th May and 21st June, 1828.

Cassini said in 1740: 'None were ever seen to last so long as that which was seen in November and December 1676, and again in the month of January 1677, having remained upon the disc of the Sun for a period of seventy days.' But the great spot of 1779 remained visible for six months, and in 1840

Schwabe saw one which returned eight times, the duration of which covered 200 days, or nearly seven months.

Is it true that some spots which have disappeared show themselves again upon the solar disc after a certain interval, and at the same point of the disc, as Cassini and Lalande believed? Cassini looked upon

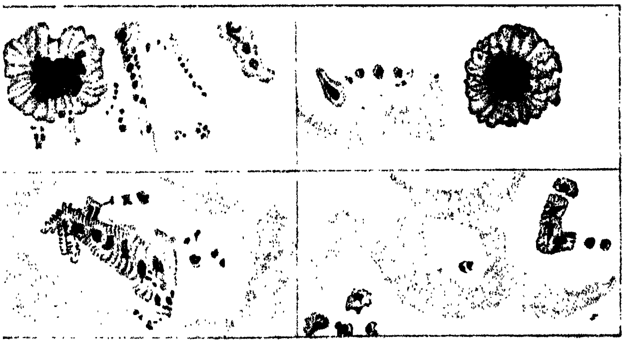


Fig. 41.—Details of two groups of Spots A and B (Fig. 40) in the interval of a rotation.

the spot which appeared in May 1702, as identical with that which had disappeared at the same point in May 1695. Lalande also asserts most positively that considerable spots reappear at absolutely the same physical points of the solar disc. According to Mr. Carrington, who has studied sun-spots during the lengthened period of seven consecutive years, it is

difficult to form an opinion on this subject and to declare the identity of the spots which show themselves in the same regions. He brings forward, however,* a considerable number of cases in which the return of the same spot offers some degree of probability. The most remarkable case is that of four groups, the first of which was visible from 24th to 30th September, 1857, the second from 16th to 18th October, the third from the 15th to 28th November, and the fourth on the 19th December of the same year. But, on account of their change of form, and slight alterations in their respective positions, it is almost impossible to establish their identity with certainty.

Certain it is, however, as the earliest observers were aware, that spots do not show themselves indiscriminately in all the regions of the solar disc. Galileo professed that they were limited to a zone extending some 29° on each side the solar equator. According to Scheiner and Hevelius this zone is 30°, and was called the *royal zone* at that period of history, as this region had the privilege of becoming covered with spots (maculated).

The width of the zone, however, increased as observation made progress, and in 1777 Messier saw a spot 41½° from the Sun's equator. In 1780 Méchain and Lalande saw another whose latitude was 40°, and about 1840 M. Laugier saw several on the 41st parallel.

* R. C. Carrington, *loc. cit.*

A group seen by Mr. Carrington in July 1858 was situated in 45° south latitude. Examples of spots being met with in higher latitudes than these are very rare: one was seen, however, by Herr Schwabe at 50°, and another by Prof. Peters, of Hamilton College, at 50½°; finally, a spot was described by La Hire as being in the 70th degree of north solar latitude, which, as Humboldt remarks, must be ranked as a very great curiosity.

Solar spots are not uniformly distributed, however, through this zone in which they make their appearance, and of which we have endeavoured to show the limits. Though they are never seen at or near the poles, and rarely beyond the 45° of latitude, they are rare enough at the equator itself, and at a few degrees only on each side of it. To render this more clear, it will be necessary to quote a few figures. In the 5290 observations made by Mr. R. C. Carrington, which comprise 954 groups of spots we only find 50 groups in the neighbourhood of the Sun's equator; 20 between 0° and + 4° latitude, 30 between 0° and – 4°; one only actually cuts the equator. The other groups were distributed pretty much as follows: about 200 up to + 10° and – 10°; 640 from these two latitudes to 30° N. and 30° S.; beyond this we have only about 60 groups. It is evidently between 10° and 30° that the spots are most abundant, as may be seen at once by a glance at Fig. 42, which is a small reproduction

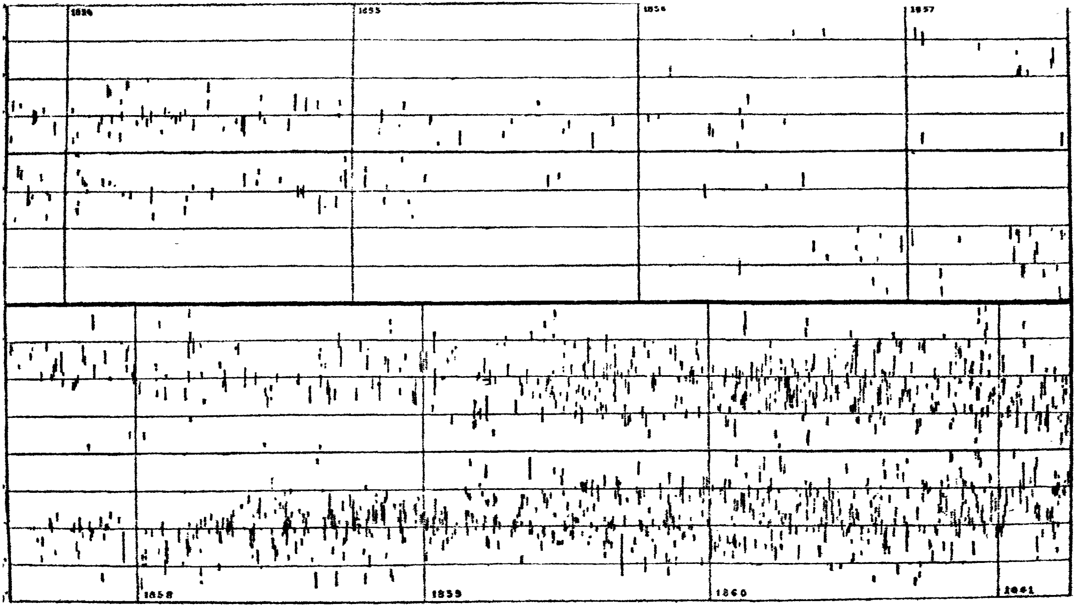


Fig. 42.—Distribution of Solar Spots according to latitude, from 1853 to 1861 according to Mr. Carrington.

of the three large plates in Mr. Carrington's work above-mentioned.

According to Sir John Herschel the actual equator of the Sun is less frequently covered with spots than the adjacent zones on each side of it, and there exists a characteristic difference between their number and dimensions in the northern and southern hemispheres; the northern spots are both more numerous and larger than those of the other zone. The region between 11° and 15° north latitude, is particularly fertile in large spots of long duration. This opinion, which is reproduced in the 'Cosmos' of Humboldt, is contradicted somewhat by the observations of Mr. Carrington, for of his 954 groups of spots we find 436 in the northern hemisphere and 518 in the southern. This result certainly is opposed to the opinion we have just cited, as far as the number or frequency of spots is concerned; and if we may judge from the drawings given in Mr. Carrington's splendid work, the spots of larger dimensions appear to have been equally numerous in each hemisphere. But it must not be forgotten that the observations which we are contrasting with one another were made at different periods. It may be that there exist certain periods at which sun-spots are really more numerous at one side of the equator than at the other, and reciprocally.

The figure 42, just alluded to, shows how much successive years differ with regard to the frequency of

sun-spots, The number of groups observed diminishes from 1853 to 1856, period at which a minimum occurs; it then increases rapidly to 1860 or 1861. In 1860 this number is 297, or 13 times greater than in 1856, when it was only 23.

From the date of the earliest observations to the present time astronomers have called attention to the great difference in the frequency of sun-spots according to the various epochs. Scheiner speaks of 50 spots seen all at once upon the solar disc in 1711. From 1700 to 1710 they were also tolerably numerous; in 1716 no less than 21 groups of spots were observed, among which 8 were simultaneously visible. From 1717 to 1720, still more were seen, particularly in 1719, when a kind of equatorial belt appeared to be formed by them. In 1740, and in October 1759, sun-spots were likewise very frequent. Schrœter counted 68 spots all visible at once, and at another time 81. William Herschel saw 50 in 1801, and 40 in November 1802.

Figure 43 shows how numerous sun-spots sometimes are on the solar disc even when they are of considerable size.

On the other hand, they appear to have been very scarce from 1650 to 1670, from 1676 to 1684. None were seen from 1695 to 1700, nor from 1711 to 1712. In 1710 and 1713 one only was observed. According to the astronomical correspondence of Baron Zach,

29 months elapsed from 1821 to 1823 without any spots being observed on the Sun's disc; on the 10th July, 1823, only a few made their appearance.

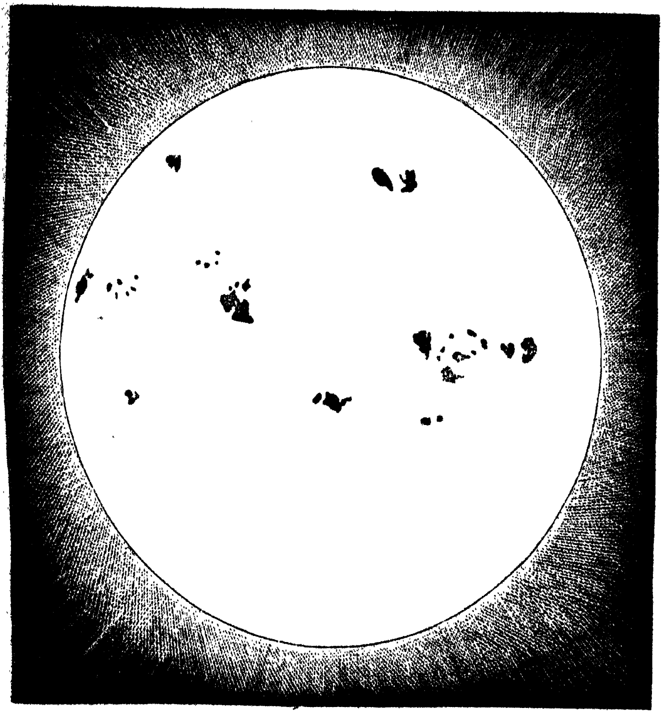


Fig. 43.—Sun-Spots, 2nd Sept., 1839, from a Drawing by Capt. Davis.

By combining and comparing together all these various data and adding to them the results of his own

observations made from 1826 to 1850, Prof. Schwabe of Dessau has placed beyond doubt the existence of a nearly regular periodicity in the occurrence of solar spots; but it is probable that the period of 10 or 11 years which results from his researches undergoes a certain variation itself. The numerous observations of Mr. Carrington, already quoted, and the continuous researches carried on at the Observatory of Kew, by Dr. Balfour Stewart and others, combined with those of Herr Schwabe, will help to solve this problem of solar physics.

In order that the eye may embrace in one glance the periods of maximum and minimum through which sun-spots have passed for more than a century, we have given in Fig. 44 the curve established by Mr. Carrington from his own researches and from those of Prof. Wolf of Zurich, who has investigated the older series of observations. Underneath are seen two other curves, the lines of which follow, more or less regularly, those of the first. One of these indicates the various distances of Jupiter from the Sun, for it appears to have been remarked that there exists a certain correlation between the proximity of that planet and the most numerous apparitions of sun-spots. The mass of Jupiter, which is relatively considerable, could it possibly have an influence on the solar surface analogous to that which the mass of the Moon exerts on our Earth and causes the tides?

This is a question which is not yet decided, but is extremely interesting.*

In the third curve given in our figure the oscillations in the price of wheat in England during this time may be seen. This curve is brought forward here because Sir William Herschel had concluded from some theoretical views of his on the physical constitution of the Sun, that the spots furnish an indication of an increase in the quantity of heat and light

* Messrs. Warren De La Rue, Balfour Stewart, and Loewy, have devoted much time to the study of solar physics, and to the probable influence of the planets Jupiter and Venus on the distribution of sun-spots in latitude. They appear to have observed that when one of these planets passes across the plane of the Sun's equator it drags, as it were, the spots into the equatorial region of the disc; they spread towards the poles on the contrary when the planet passes away from the equatorial plane (see 'Monthly Notices of the Astronomical Society,' Nov. 1866).

[Those of our readers who would wish to follow up this apparently fertile field of physical discovery would do well to consult the valuable 'Researches on Solar Physics' by the three authors above named (printed for private circulation by Taylor and Francis, London, 1866), and also the papers communicated by Prof. Balfour Stewart on this subject to the 'Proceedings of the Royal Society.' It is certainly one of the most interesting and important discoveries of modern times, should future research confirm it, that planets far removed from the Sun, can cause mechanical changes on so vast a scale as that exhibited by sun-spots. Compare also the very interesting paper by Camille Flammarion, entitled 'Le Soleil, sa Nature et sa Constitution physique' in his excellent 'Etudes et lectures sur l'Astronomie,' published at Paris, in 1867.—P.]

Fig. 44. - Curves representing, 1st. the Variations in the number of Sun-Spots from 1750 to 1860; 2nd, the various Distances of Jupiter from the Sun; and 3rd, the Price of Wheat during this Period.

emitted from the regions where they occur. These radiations would, therefore, be more intense when the spots are most numerous, and hence the mean temperature of the Earth would vary somewhat on these occasions. In order to prove this, the illustrious astronomer, not having sufficient meteorological data at his disposal to solve the problem, sought for another test, and took the price of wheat as a term of comparison; he thought he had found that for a period extending over about two centuries, the price of wheat had been higher when the Sun had shown the least signs of spots.

The question was examined again by M. Gautier of Geneva. F. Arago and M. Barratt made still more complete tabulations, taking into account the numerous results furnished by modern meteorological researches; and their conclusions contradict those of Herschel. However, this is a problem which can only be completely solved by a still greater accumulation of comparable facts. If there exists a connection between the spots of the Sun and the temperature of the Earth, it is by comparing the mean temperatures of a great number of countries, situated in different latitudes, and in all parts of the world, that the fact will be proved.

As Arago truly remarks, 'In these matters we must be careful how we generalise facts before we have a very considerable number of observations at our disposal.'

The periodicity of sun-spots has been placed in connection with another terrestrial phenomenon, namely, the motions of the magnetic needle. The diurnal variation of this apparatus has also a maximum and a minimum, the period of which appears to be about ten years, and to correspond with the period of sun-spots. It results from observations made in recent times by Prof. Wolf, Prof. Secchi, and General Sabine, that the epochs of greatest frequency of solar spots are those in which the greatest perturbations of the magnetic needle have been noticed. According to Wolf, however, there would be three different periods, either for the spots, or for the needle, and particularly for the aurora borealis: the first appears to be 11 years 40 days, the second $55\frac{1}{2}$ years, and the third 166 years. Are these accidental connections, or are they really due to a magnetic influence which the Sun exerts upon the Earth?

§ 4. What are Sun-spots?

Various conjectures concerning the Physical Constitution of the Sun—Theories of Wilson and W. Herschel—The Spots are Cavities—The Photosphere is an Incandescent gaseous substance.

Until now we have remained strictly within the limits of actual observation, that is to say, within the bounds of positive facts furnished by science: we are

now about to penetrate into the domain of conjecture and hypothesis in endeavouring to reply to a question which many thousands of people, both ignorant and learned, have asked already, and which many of our readers have doubtless asked themselves whilst perusing this little volume.

What is the Sun?

If the science of astronomy could solve this great problem, it would be nearly capable of solving that of the entire Universe, at least so far as we know, for we have already seen that such a question is equivalent to asking,—

What is a star?

As our readers will easily imagine, all the theories exhibited for the last 250 years, that is, since the Sun was first observed with a telescope, are based upon the phenomena presented by sun-spots. It was, therefore, essential to describe with some detail all the peculiarities of their structure, their formation, and their real or apparent motions, their periodicity, and their distribution on the surface of the immense sphere. We have done so; let us now review the hypothesis in question.

When it was once proved — and it was not long in being so — that the spots certainly belonged to the body of the Sun itself, the various observers gave each his own opinion of them.

Galileo, first of all, regarded the spots as a kind of

smoke, as clouds, or froth, formed on the surface of the Sun, and swimming on an ocean of subtle or fluid matter. Helvelius was of the same opinion as the great Florentine. Other persons also considered the spots to be something floating on the surface of the Sun; but sometimes it was thought to be bituminous matter expelled from sunken volcanoes, or irregular solid bodies plunged in a fluid, and appearing from time to time at its surface. The following lines show how Cassini II. exhibited the various opinions current on this subject in his time; he has been prudent enough, however, not to give his own opinion in favour of one or the other conjecture.

'Some people,' says he, 'believe the Sun to be an opaque body having an irregular surface somewhat like that of our Earth, its irregularities being entirely covered over by a luminous fluid matter; that this fluid being drawn towards certain parts more than to others by a kind of tide action allows us to see now and then one or more of these points or rocks underneath; this produces the appearance of spots, around which exists a kind of froth or spray represented by the nebulosities (penumbræ); that the spots disappear when these points are again covered by the fluid, and appear again when the fluid moves off to another part: this explains tolerably well why they reappear on the same portion of the Sun's disc after a certain number of revolutions.'

This first opinion is that of La Hire, which Lalande still regarded in 1764 as the most probable. At the present day, since the proper motion of the spots on the Sun's surface has been proved by so many direct observations, it is unnecessary for us to refute an opinion which requires them to be perfectly immoveable, and is, moreover, in contradiction with the appearances presented by the penumbra, always darker near the the borders than next to the nucleus.

'Others,' continues Cassini, 'have imagined that the centre of the Sun is an opaque dark nucleus, entirely covered by luminous fluid matter; that in this opaque body there exist volcanoes similar to Vesuvius and Etna, which throw out, from time to time, masses of bituminous matter, which find their way to the surface of the Sun, where they produce the effect of spots, in the same manner that a new island was formed in the Archipelago near Santorin and another near the Azores; that this bituminous matter is altered or decomposed by that which covers the surface and which gradually consumes or dissolves it, forming those nebulosities and transformations which are remarked in the spots; the latter disappearing when this bituminous matter is completely consumed or destroyed; that they appear again, however, at the same points of the solar disc, when the volcanoes throw up another lot of bituminous matter.

'Some have concluded that the Sun is composed

of a fluid matter in which certain irregular solid bodies are plunged, and that these are sometimes brought to the surface by the motion of the fluid appearing as spots, the forms of which differ with those of the said irregular solid bodies.

'Lastly, others have imagined that the Sun is formed of a subtle fluid matter in a constant state of agitation; that the gross matter contained in the former is separated from it by the rapid motion of the fluid, and is carried to the surface in the form of froth and foam, like that which appears on a melted metal or any other boiling matter, this scum is moved about by the fluid matter of the Sun, and so appears in the different shapes and aspects taken by the spots, which we see, independently of optical illusions, increasing or diminishing in size, approaching or receding slightly to or from each other, and disappearing when dissipated entirely by the constant agitation of the subtle matter of which the Sun is composed.'

These primitive explanations of sun-spots are only rough interpretations of the phenomena as they were first observed: the spots had not been studied in all the details of their movements and their structure; and the necessity of explaining the latter was, of course, not then felt. It is to be remarked that the two first conjectures suppose that the spots always make their appearances at the same points of the disc, as they admit them to depend on rocks or scoria from

volcanoes in fixed positions. The two others resemble the preceding very much, since they also make out the spots to be solid bodies, scoriæ, &c., but they differ widely in an important point, viz., they consider the spots movable, and therefore capable of showing themselves in any regiou of the solar disc.

It is useless for us to linger over these first rough sketches of a theory of the Sun; the reader will easily perceive, from the descriptions of the detailed observations of solar phenomena, their principal defect, that is, their inadequacy to explain these phenomena.

Let us now examine a theory imagined by the Scotch astronomer Alexander Wilson, a very ingenious theory subsequently modified and completed by Bode, and by William Herschel, and afterwards adopted and perfected by a considerable number of more modern philosophers. In spite of the serious objections that have been raised against it of late years, there are still many distinguished men who adhere to it. We must leave aside the history of the different phases through which this theory has passed, however instructive such a history may be, and shall, therefore, limit ourselves to the exhibition of it, as given about twenty years ago by Arago in his 'Astronomie Populaire.'

It is essentially distinguished from the older theories by considering the spots to be, not solid bodies emerging and floating on the photosphere, but cavities existing momentarily in the luminous envelope of

the Sun and permitting us now and then to view the internal and less luminous portions of the solar globe.

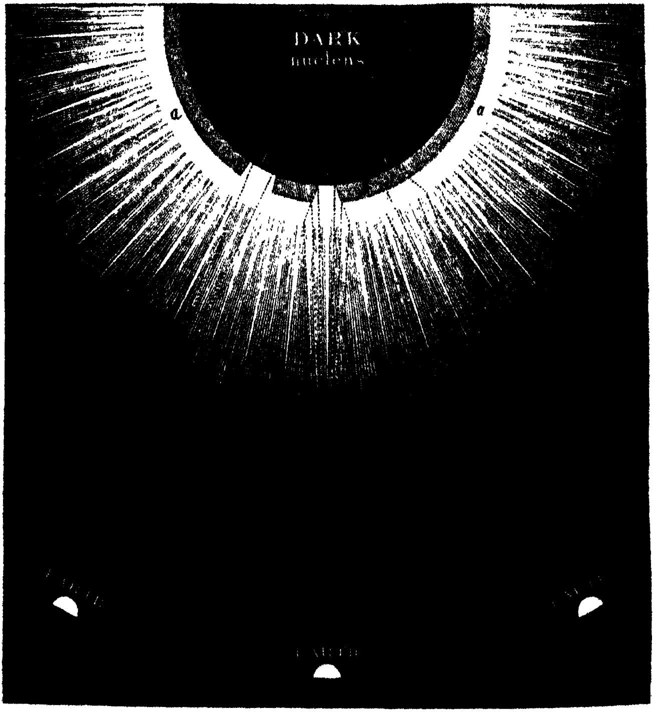


Fig. 45.—Explanation of the Phenomena of the Spots by the theory of Wilson and Herschel: *aaa*, Photosphere; *bbb*, Lower Cloudy Atmosphere; A, Spot with its Nucleus and Penumbra; B, Nucleus without Penumbra; C, Penumbra without a Nucleus.

The entire globe would, according to this theory, be formed in the following manner:—

'In the first place, internally, we have a spherical nucleus, relatively obscure, surrounded at a certain distance by a first atmosphere *b b b* (fig. 45), which may be compared to the Earth's atmosphere, when the latter is occupied by a continuous layer of opaque and reflecting clouds. If we place above this first layer a second luminous atmosphere *a a*, which we will call the *photosphere*, this, more or less distant from the lower cloudy atmosphere, will determine the visible periphery of the central orb.'

Let us see now how this theory accounts for the appearances presented by sun-spots and the dark or light portions of the disc.

We may imagine that gaseous matter is formed from time to time at the surface of the dark nucleus, the high temperature of which causes its deflagration, or that this surface is strewed with foci of volcanic action which rupture, from time to time, the two atmospheres of the Sun, producing cavities through which we get a glimpse of the dark central nucleus.

Such openings would generally have the form of irregular cones, widened at their external surfaces, allowing the solid dark body of the Sun to be seen through their narrow ends, and the cloudy atmosphere of a grey tint all around. Hence the appearance of black spots surrounded by penumbra.

But it may happen that the opening is wider in the cloudy atmosphere than in the luminous envelope,

or photosphere; in this case the dark nucleus alone would be seen, and we should have a spot without a penumbra. Again, the rupture of the first grey envelope becoming closed before that of the photosphere, would have for effect to shut out the view of the dark globe, and we should have a penumbra without a nucleus. A violent and sudden outbreak occurring in a gaseous mass, such as the photosphere is supposed to be, would produce all around the opening a condensation of the matter of which the photosphere is formed; hence an increased luminosity in these parts giving rise to what are called *faculæ*, which almost always surround the spots.

This theory of the physical constitution of the Sun accounts in a tolerably satisfactory manner for the various phenomena observed in detail on the solar disc. The various forms of the spots, their disappearance, even their motions, are thus explained in a very natural manner. The fact often noticed, that the nucleus of a spot diminishes gradually, and is finally reduced to a small point before disappearing entirely, leaving the penumbra for a short time alone, is perfectly explained by it. It is easy to conceive also by its aid how the faculæ subsist for some time after the disappearance of a spot, and even become somewhat more intense, for a certain interval would certainly be required before the perfect uniformity of the gaseous layers, or atmospheres, could be re-esta-

blished; the gaseous matter would precipitate itself into the vacuum formed by the rupture, and being condensed would become more luminous.

Besides ascending currents, rapid and powerful enough to rupture the atmospheric envelopes of the Sun, we may imagine that a continual agitation exists in these gaseous strata and on the surface of the photosphere. This surface would be, therefore, not smooth, but rough, having eminences and depressions in every direction, like the waves of the ocean. Hence those lines of light and shade, luminous and obscure ridges, which have been called *luculæ;* hence also that multitude of *pores* which cause the disc of the Sun to appear covered with points, to which we have already alluded.

All these explanations of the phenomena presented by sun-spots are based upon two hypotheses: the first admits that the spots are cavities in the luminous envelope; the second, that the nucleus of the Sun is a dark globe, and that the light of the photosphere is that of a luminous incandescent gas. It remains for us to see whether these two conjectures can be supported by the results of actual observation.

In the first place let us inquire, Are the spots really openings or cavities in the photosphere?

To present the subject in its clearest light, let us consider a circular spot, the black nucleus of which is surrounded by a penumbra of nearly equal width all

round; and let us suppose that it changes neither in size nor in form during the whole of its passage across the solar disc, from the eastern to the western limb. It is only when at the centre of the disc that an observer would see it in its true form, which would be that of two concentric circles, or a black circular object surrounded by a greyish-coloured ring. Before it arrives at the centre of the disc, and after it has passed over this centre, the effect of perspective will, of course, cause a deformation of the spot, its true dimensions will be preserved parallel to the axis of rotation, but its width will shrink, and it will become more and more narrow as it approaches the border or limb of the disc. There it will be seen as two concentric ovals.

If the spot and its penumbra are merely superficial accidents of colour entirely on the surface of the photosphere, what should we see in such a case?

It is evident that the greyish ring forming the penumbra would appear narrower at that side of the spot where the obliquity of the visual rays is greatest; that is, on the side nearest the edge of the Sun; and this inequality in the width of the penumbra would be the more noticeable the nearer the spot gets to one of the Sun's edges.

If the spot is an eminence, or something projecting from the surface of the disc, the above effect would be still more striking, and the black centre in this case

would, when seen in perspective, quite mask that portion of the penumbra nearest the edge; this portion would disappear completely whilst that part of the penumbra turned towards the centre of the disc would remain visible.

Lastly, if the spot is a cavity of which the penumbra forms the sloping sides, we should see exactly the reverse; we should see what we have represented

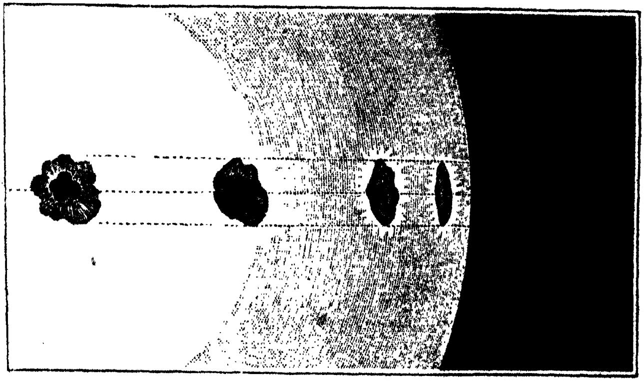


Fig. 46.—Aparent change in the form of a Sun Spot as it moves from the centre to the edge of the disc.

in fig. 46, where the apparent change in the form of a sun-spot as it passes from the centre to the edge of the disc is depicted. It is that portion of the penumbra turned towards the centre of the disc, which first begins to diminish in width, and which actually disappears altogether, whilst the other portion seen

less obliquely as the motion progresses, appears to increase in size. Very near to the edge, an instant occurs when the black nucleus, which is the bottom of the cavity, disappears from our sight; then the penumbra getting thinner and thinner as it nears the edge, disappears likewise before touching the Sun's border.

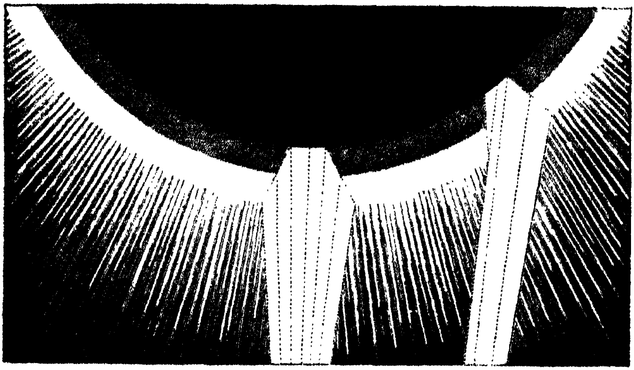


Fig. 47.—Explanation of the change of form observed in the nucleus and the penumbra in Alex. Wilson's hypothesis.

Such were precisely the appearances observed by Wilson in 1769, which suggested to him the hypothesis referred to above. Since then numerous observations, and several new arguments which seem to us thoroughly decisive, have confirmed this particular point in the Sun's history, and it appears therefore to be well

proved that the spots are really openings in the Sun's photosphere.

M. Faye, in alluding in some of his writings to these decisive proofs, quotes a remarkable observation made by Galileo, and often repeated since his time. Two spots being seen near to each other at the centre of the disc, and separated only by a thin strip of light, it is evident that if the spot nearest the centre was a prominence on the Sun's surface, this strip of light would soon be masked by it, whilst in reality it remains visible to the very edge of the disc, diminishing in width only according to the laws of perspective.

In a letter we received from M. Chacornac in 1865, he lays great stress on this fact, namely, that if the spots were prominences, such as clouds, &c., 'they would never be seen to disappear before they arrived at the edge of the disc,' a thing which is, on the contrary, generally observed.

If once we admit that sun-spots are cavities, or ruptures in the luminous photosphere which envelopes the Sun, it is difficult to guard against the illusion which causes us to imagine the existence of a hole when we see a black spot detaching itself upon a lighter background. In fig. 48 we have a spot which appears like a gigantic whirlwind or cyclone—an immense funnel into which the luminous matter of the photosphere is being engulfed and absorbed.

But such an illusion would not have sufficed to explain the appearances presented by sun-spots, without the aid of actual observations. A curious experiment by Mr. Warren de la Rue turns such an optical illusion into an argument which tends to transform it into a reality. This learned and ingenious

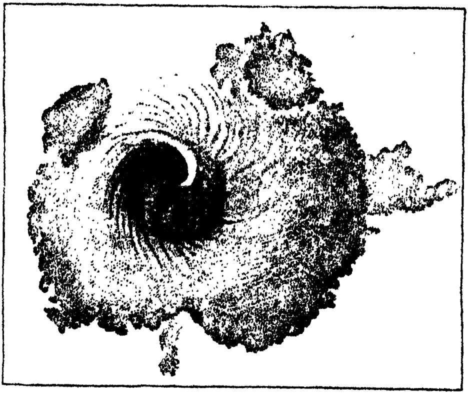


Fig. 48.—Spot presenting the appearance of a whirlwind or cyclone observed by Prof. Secchi on the 5th May, 1857.

astronomer took some photographic views of the same spot at two days' interval, in order to obtain them under the proper visual angle to produce *relievo* in the stereoscope; and when seen in this instrument, the photograph shows the spot most perfectly as a funnel-shaped cavity.

On the 16th November, 1868, M. Delaunay pre-

sented to the French Academy of Sciences a photograph of the Sun, recently obtained by Mr. Warren de la Rue. This picture was taken just as a considerable sized sun-spot was exactly on the edge of the disc. At this point we see in the photograph a hollow excavation, which indicates most plainly the existence of a cavity in the photosphere where the spot occurred.

Lastly, by investigating a very large number of spots, and measuring the width of the penumbra to the right and to the left of the line which represents the Sun's axis on the disc, the astronomers of Kew have obtained results in accordance with the hypothesis in question. In 605 different cases 75 gave no results, that is to say, the penumbræ were of equal breadth on each side of the line; of the remaining 530, 456, or 80·04 per cent, presented appearances in accordance with Wilson's hypothesis; 74, or 13·96, per cent, presented a contrary appearance.* By measuring the length of the penumbra, as they measured its breadth, the same authors found that the foreshortening or perspective view of the spots was such as is required by Wilson's hypothesis. 81 per cent of the spots had their penumbræ wider towards the poles than at the side next the centre of the disc.

* De La Rue, Balfour Stewart, and Lowey, 'Researches on the Solar Physics,' 1st Series, 1865.

It appears then to be clearly proved that the spots and their penumbræ are holes or cavities which appear from time to time in the Sun's photosphere. This first part of the theory appears to be incontestable; let us see whether the second point is as probable, that is, whether the globe of the Sun is formed by a dark nucleus, surrounded at a certain distance by two envelopes or atmospheres—one not self-luminous, but capable of reflecting light; the other self-luminous, forming the visible periphery of the Sun itself, and being the source of its luminous, calorific, and chemical radiations.

In the first place, is the photosphere formed of an incandescent gas at a high temperature, as the theory supposes it to be? or is it more probably a liquid ocean, a mass of molten matter, or a solid body in a state of incandescence?

If the spots are really cavities, the two last notions may be rejected at once, for if these cavities were produced in a liquid, it is incredible that they should last so long, or that the equilibrium of the masses which form the sloping sides should remain disturbed for days, weeks, or months together; in fact, that these enormous excavations are not at once filled up. And if the photosphere is composed of solid matter, the spots would have to be considered as external bodies projecting from the surface of the solar globe.

Nevertheless, these are only negative proofs. Arago

has supplied a positive argument in favour of the gaseous nature of the photosphere. According to some of his experiments, light which emanates at a very small angle from a solid or liquid body in an incandescent state constantly shows traces of *polarisation.** Light which comes to us from the edge of the Sun should, therefore, be more or less *polarised,* if it emanated from a liquid or a solid substance; received in a polariscope, such light would be decomposed into two beams of complimentary colours. Such, however, does not occur, and observation proves that at whatever angle, or at whatever region of the disc it is examined, the light of the photosphere is always in the natural state, such as emanates from an incandescent gaseous substance; 'to be precise,' says Arago, 'such as illuminates our shops and lights our streets.'

This experiment, which appears so decisive and to prove so incontestably the gaseous nature of the

* The meaning of the terms *polarisation*, *polarised light*, and *natural light*, which we cannot stay to explain here, is fully given in works on Optics, or treatises on Physics. [Light which is polarised possesses certain properties which distinguish it from natural light. It may be polarised in several ways; for instance, by reflection at a certain angle from polished surfaces, by transmission in certain directions through crystals, &c. Light which is supposed to be polarised is tested in an instrument called a *polariscope*, invented by Arago, and in which it reveals by colour, &c., some of its peculiar properties.—P.]

Sun's photosphere, has been nevertheless called in question;* and it has recently been put to the test of another optical experiment no less important, which we will now refer to, as it has been attempted to deduce from it a new theory of the physical constitution of the Sun.

§ 5. Contemporary Views regarding the Physical Constitution of the Sun.

Spectral Analysis of Solar Light and Theory proposed by Kirchhoff, Bunsen, and Mitscherlich.—M. Faye's Theory.

When the light of the Sun is decomposed by its passage through a prism, it produces an image formed of various colours, arranged in a constant order, and known as the *solar spectrum.* This spectrum is, moreover, crossed by a multitude of dark lines, some wider than others, and more easily seen, but a vast number too fine to be distinguished without the aid of special apparatus.

A light emanating from any other source than the Sun gives also a spectrum when it is caused to

* [Sir John Herschel has intimated in his 'Astronomy,' that the rays emanating from the edge of the Sun cannot be totally composed of the exceedingly oblique beams of light supposed by Arago, and that this experiment, in appearance so conclusive, really leaves the question pretty much where it was before.—P.]

pass through a prism; but, according to the nature of the source of light, the different spectra can be distinguished from one another by certain special characters, and at present these distinct kinds of spectra are arranged as follows:—

A *spectrum of the first order* forms a continuous coloured band quite uninterrupted by dark lines, or by brilliant lines. The light which produces such a spectrum is that which emanates from a solid or liquid body in a state of incandescence, but opaque. Lime, iron, magnesia, &c., heated to a temperature at which they become luminous, give a spectrum of the first order.

A *spectrum of the second order* is formed of luminous coloured lines, separated by wide dark intervals. Such a spectrum is produced by gaseous sources of light, and according to the nature of the gas examined the bright lines vary in number, in position, and in colour. Hence it is possible to investigate chemically any gases present in a flame, and to determine their nature by the lines observed in the spectrum of this flame.

Lastly, a *spectrum of the third order* is that in which dark or black lines interrupt the continuity of the coloured band; such a spectrum is produced by a beam of sun-light. Now a few years ago the German Professors Kirchhoff and Bunsen explained how these dark lines are produced in the luminous spectrum.

They showed that the *bright* lines which form the spectrum of an incandescent gaseous substance are transformed into *dark* lines when a more intense source of light capable of giving a continuous spectrum is placed behind the flame.

Thus the lime-light (or Drummond light), which is produced by lime rendered brightly incandescent, gives a continuous spectrum, and the faint flame of a spirit-lamp burning alcohol saturated with common salt gives for its spectrum one single yellow line, which occupies the place of the line D of Fraunhöfer in the solar spectrum; this line is characteristic of sodium; it is sometimes called the sodium-line. Now if this spirit-flame be placed between the eye and the Drummond light, there appears at once in the continuous spectrum of the latter the black line D. It is this phenomenon which Professor Kirchhoff calls the *reversal of the spectrum of flames;* and he has found that it occurs with all the metallic substances, besides sodium, which he has been able to examine. A spectrum of the third order is, therefore, one produced by light emanating from a solid or liquid substance in a state of incandescence, but which light has passed through a gaseous matter, an atmosphere of absorbing vapours, before reaching our eye.

On generalising these curious results of their experiments, the two philosophers above named came to the conclusion that the *black lines* with which the

Solar spectrum is striped point to the reversal of so many *bright lines* by the presence of a layer of gaseous matter placed before the luminous photosphere of the Sun. This photosphere acts towards us as the Drummond light in the experiment just referred to; a gaseous atmosphere envelopes it, and holds in suspension the vapours of various metallic substances, playing the part of the spirit-lamp flame in which salt (chloride of sodium) is volatilised.

Hence the unexpected and exceedingly interesting discovery that by studying attentively the 2000 and more dark lines seen in the solar spectrum we may be able to make a qualitative chemical analysis of the Sun's atmosphere, and determine by simple observation through a powerful prism of what metals or other elementary substances* the globe of the Sun is composed.

For instance, seventy of the *bright lines* in the spectrum of iron, varying in colour, in breadth, and in intensity, coincide so perfectly with seventy *dark lines* of the solar spectrum, that it is impossible to doubt

* [Elementary substances or elements are substances which cannot be decomposed into two or more other substances, such are sulphur, iodine, iron, silver, sodium, &c.; they are each characterised by one or more lines in the spectrum, and by combining together in certain definite proportions from all known bodies. The art of discovering the presence of one or more elements in a compound or a mixture, by means of the prism, is termed *spectral analysis.*—P.]

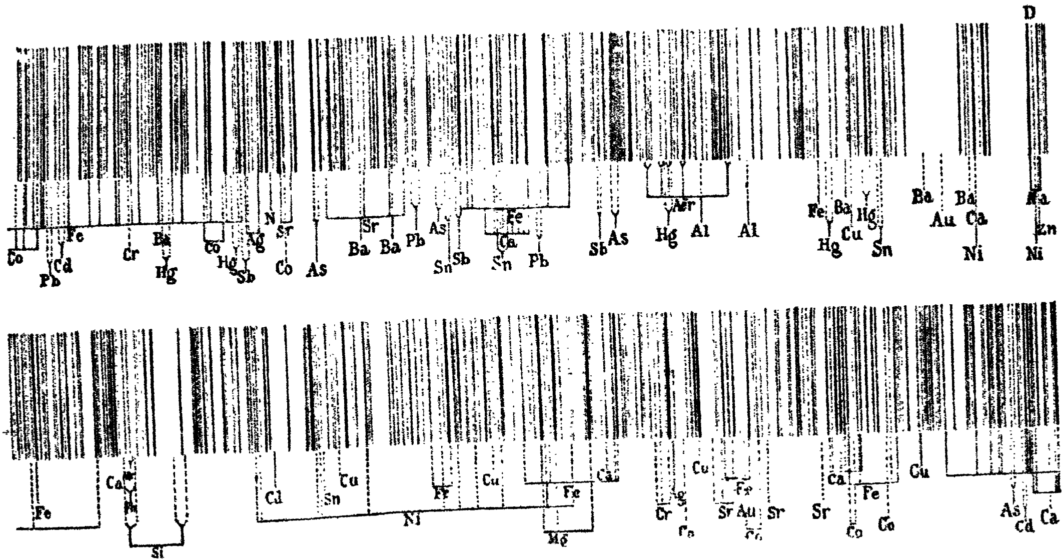


Fig. 49 —Fragments of the solar spectrum showing the dark lines, and their coincidences with the metallic spectra. Fe, iron lines, Na sodium line, Co. cobalt line, Mg. magnesium Ca. copper, &c. &c.

that iron vapour exists in the Sun's atmosphere. In Fig. 49 a certain number of these lines are seen, marked Fe. In this manner the Sun's atmosphere has been found, by actual observation, to contain iron, copper, zinc, chromium, nickel, magnesium, calcium, sodium, and hydrogen; it is probable that it contains also cobalt, strontium, and cadmium. On the other hand, neither gold, silver, nor platinum, has been detected in it: it is rather singular that the glorious orb to which the old alchymists dedicated gold should contain none of the King of metals.*

These results yielded by the spectral analysis of various sources of light lead to the conclusion that the solar spectrum is a spectrum of the third order, *i.e.* a spectrum produced by a luminous source capable of yielding a continuous spectrum, before which source

* This conclusion deduced from Prof. Kirchhoff's results is, however, too absolute: more recent spectral investigations made by the late Prof. Mitscherlich show that the presence of certain substances in a flame may prevent the spectrum of other substances being properly observed by extinguishing their principal lines. Thus, if a flame containing chloride of strontium, and producing the peculiar spectrum of this metal, be caused to take up also the double chloride of copper and ammonium, the blue line which characterises strontium, disappears at once. [Moreover, if we admit, with the celebrated astronomer, Laplace, that all the planets have been formed from the Sun, it is tolerably evident that not only all the elements which constitute our Earth exist also in the Sun, but probably many others beside.—P.]

is placed a gaseous absorbing atmosphere. Hence the following theory of the physical constitution of the Sun proposed by Prof. Kirchhoff:—

'The visible portion of the Sun, that which is limited by the periphery of the disc, the surface of which constitutes the photosphere, is a solid or liquid sphere in a state of incandescence.

'This nucleus, the temperature of which is very high, is surrounded by a very dense atmosphere, formed of the elements which constitute the incandescent globe itself, whose extremely high temperature maintains them in the state of vapour or gas.'

If this is the case, the spots can only be accidental occurrences outside the photosphere, something projecting above its surface. How are they explained in this new theory? In the following manner:—

Prof. Kirchhoff admits that from some unknown cause certain points of the Sun's surface undergo a temporary cooling, which has for effect a condensation of cloudy matter, such as we observe in our own atmosphere when watery vapour condenses into clouds by cooling. A dense agglomeration of vapours in the form of clouds, intercepting the rays which emanate from the luminous body of the Sun appears to us like spots upon its disc. A cloud once formed in this manner, acts as a screen towards the higher regions, hence a cooling effect in these regions also, and the formation of another cloudy layer less dense, less

opaque, which seen from the Earth has the appearance of the penumbra that surrounds the spots.

In this hypothesis the apparent deformations which a spot undergoes, as it moves from the Sun's edge to the centre, or from the centre to the edge, are explained as an effect of perspective which is represented in Fig. 50.

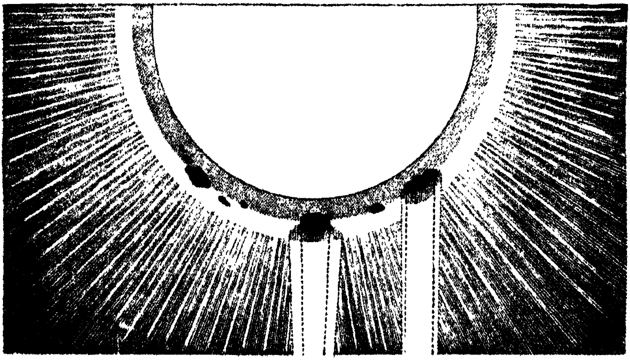


Fig. 50.—Explanation of Sun-spots in Kirchhoff's theory—Solid or liquid incandescent nucleus; superposed clouds.

Seen in front the spot will, of course, appear to occupy the centre of the penumbra; but as it travels towards the Sun's edge, that portion of the upper cloud situated nearest the centre of the disc, will be projected upon the dark nucleus and be confounded with it, whilst the other portions of the same cloud nearest the limb will appear wider, the visual ray passing through the entire thickness of this cloud which floats above.

Such is the new theory which, as we see, is a complete contradiction of the foregoing admitted by Wilson, Herschel, and Arago. The former supposed the spots to be openings in the photosphere, whilst Kirchhoff, renovating the old notion of Galileo, looks upon them as clouds suspended in the Sun's atmosphere. On the one hand the polariscope observations made by François Arago tend to establish that the photosphere is an incandescent *gas;* on the other, spectral analysis tends to prove that it can only be a *solid* or *liquid* substance in a state of incandescence.

This is a contradictory state of things which has latterly overturned all our ideas concerning the physical constitution of the Sun. Before exhibiting the attempts which have been made to conciliate the two theories, let us examine some of the objections which can be raised against both, let us point out their respective values and their insufficiency.

The old theory regards the Sun's nucleus as a relatively cold and dark body. How is it possible, then, to explain that the calorific radiations of the photosphere which extend to such an enormous distance into space are without action upon the neighbouring layer of internal atmosphere, and are not conducted to the Sun's nucleus itself? It is evident that such an intense source of heat which does not appear to have diminished in intensity for millions of years separated only by a few hundred miles from a cold

and dark mass of matter, is a notion completely at variance with all known physical laws.

The same theory does not account either for the different velocities given for the Sun's rotation, as deduced from the equatorial spots or from those situated in higher latitudes; neither does it explain the unequal distribution of the spots in the two zones on each side of the solar equator where they appear.

But the new theory, it cannot be denied, is subject to objections quite as serious. If it accounts, like the old one, for the eccentricity of the nucleus and penumbra of a spot near the border of the disc, it is in contraction with positive and numerous observations which teach us that the nucleus becomes invisible before it arrives at the edge of the disc. It explains neither the faculæ nor the pores, nor the curious granulations known as 'willow-leaves;' it does not tell us why spots are never formed in the polar regions and why they are so abundant in the two zones at each side of the equator.*

After weighing all these difficulties a French astronomer, M. Faye, has lately taken up the discussion and proposed a new or modified theory which, he thinks, enables us to explain all the phenomena ob-

* [It must be confessed that these appear to be rather weak objections to Kirchhoff's theory in comparison to those raised by the author against Wilson's.—P.]

served and is not subject to the objections referred to above.

M. Faye starts from a fact which appears to him incontestably established by direct observation, namely, that the spots are cavities in the photosphere of the Sun. He opposes to Kirchhoff's theory the objections we have briefly indicated, and so far pronounces himself in favour of Wilson's theory. With the partisans of the latter he admits that the photosphere is formed of gaseous matter, relying upon the polariscope observations made by Arago which he deems conclusive evidence on this point, the light emanating from the edge of the Sun showing no polarisation. But he wanders completely from the views entertained by William Herschel by considering the entire nucleus of the Sun as composed of gas; the hypothesis of a cold nucleus appears to him, as to the German physicist, to be a physical impossibility. That touchstone of all theories, the phenomena of the spots with their dark nucleus and their penumbra, their peculiar apparition, and their movements, all that is accounted for in Faye's theory in the following manner.

The Sun and all the stars which shine in the depths of space, and which, according to the ideas generally adopted by modern astronomers, are in no way distinguishable from our Sun, would have been originally formed 'by the successive combination of vast masses of matter under the influence of attraction,

which matter was originally dispersed through space in all directions. Hence two immediate consequences; 1st, the destruction of an enormous amount of *vis viva*, replaced by an enormous development of heat; and 2nd, a movement of rotation more or less slow affecting the entire mass.'

A homogeneous gaseous mass such as this, whose internal temperature is far higher than the degrees at which chemical action begins, having a radiating or emissive power of very slight extent, for its radiations would, of course, be entirely superficial, and a conducting power quite as slight, would have its equilibrium disturbed only very slowly and gradually. 'Unless, indeed, we suppose something more, we cannot see how this mass could emit the enormous amount of heat that the Sun radiates now for so many series of centuries apparently without any loss.' To solve this difficulty M. Faye remarks that the measure of the intensity of solar radiation proves that the temperature of the surface of the solar globe is far from being so high as the internal temperature which his theory supposes the body of the Sun to possess. Hence the action of molecular forces, of cohesion, affinity, &c., which cannot exist in the interior, are capable of manifesting themselves at the surface. Hence precipitations, clouds of non-gaseous particles, capable of passing into an incandescent state. 'After a while these particles, influenced by gravitation will fall to

the lower strata, where they will meet with a temperature of dissociation,* whilst they will be replaced in the superficial layers of ascending currents of gaseous matter, afterwards engulfed in their turn. The general equilibrium will thus be evenly disturbed in a vertical direction, by a constant change going on from the inside to the surface, and as the internal mass is enormous compared to this surface, it is easy to conceive that the superficial emission of heat, fed incessantly by the vast central reservoir of caloric, must constitute a state of things of very long endurance and of great constancy.' The existence of the photosphere is thus explained; according to this theory it is a simple effect of cooling. It remains for us to see how it accounts for the spots.

According to M. Faye the spots are owing to the vertical ascending and descending currents just alluded to; where the former predominate the luminous matter of the photosphere will be temporarily dissipated. 'Through such an opening it is not the "dark," "solid," "cold" nucleus of the Sun, which is seen, but the internal gaseous matter, whose radiating power, even at the highest temperature of incandescence, is so slight compared to that of the surrounding luminous

* [Temperature at which chemical action is impossible, or at which a body is split up into its component parts. This temperature, like the boiling point, or the point of fusion, differs for each particular compound.—P.]

clouds of non-gaseous matter, that the difference is quite sufficient to explain the contrast of tint observed when the Sun is viewed through a dark glass.'

In the next place M. Faye shows that the law deduced from Mr. Carrington's observations, viz. that the different zones of the photosphere are subject to a retardation in their revolution which is proportional, or nearly so, to the squares of the sine of their latitudes, is a consequence of the rupture of equilibrium produced by the currents.*

* 'The ascending masses,' he says, 'coming up from a great depth arrive at the surface with a linear velocity of rotation less than that of the surface itself, because the strata whence they start have a smaller radius. Hence, a general retardation in the motion of the photosphere, although this retardation is compensated for, as regards the total mass, by the descending currents, so that the fundamental law of the areas is perfectly satisfied. If the photosphere is behindhand in respect to the general rotation, the deeper layers to compensate for this will be in advance of the general movement. It results from this opposite state of things that whilst the photosphere has only a slight tendency to approach the axis of rotation by spreading itself superficially towards the poles, a contrary tendency manifests itself in the lower strata which will move towards the equator. The phenomena occur as if the starting-points of the vertical currents were upon an internal surface more distant from the poles than from the equator; and if the imaginary surface of radiation was spheroidal for instance, its depth, and consequently the retardation of the successive zones of the photosphere, would vary very nearly as the square of the sine of the latitude.' ('Comptes-Rendus de l'Acad. des Sciences,' 1865, i.)

Finally, he endeavours to show that the experiment of Arago on the non-polarisation of the light emanating from the borders of the disc, and those of Kirchhoff on the lines of the spectrum, are, perhaps, not so contradictory as some might imagine. Arago spoke of a gas, such as coal-gas, in which the solid incandescent particles produce the brilliancy of the flame,* and not of the obscure flame of a simple gas. On the other hand, those who have concluded from Kirchhoff's experiments that the photosphere is a liquid substance 'have not reflected that incandescent particles diffused in a gaseous medium which is itself at a very high temperature, would give a continuous spectrum, except where black lines occurred resulting from absorption by the gaseous medium.'

In 1852, M. Chacornac called attention to the fact that sun-spots have a tendency to form groups elongated in the direction of the movement of rotation; those which have the largest and blackest nucleus, and which persist the longest frequently precede a long train of spots parallel to the solar equator. When the group disappears by being covered over by the faculæ which follow behind, it is the spot which is

* [This is contrary to Dr. Frankland's experience. This distinguished chemist has, indeed, shown lately that the luminosity of flames is not owing to solid matter in suspension; but his experiments were not made when M. Faye published his extraordinary theory.—P.]

the farthest advanced in the direction of the rotation, that disappears the last. This peculiar disposition of the faculæ behind the spots, that is, to the left of them has been confirmed by the observations of Messrs. Balfour Stewart and Warren De La Rue. Of 1137 spots which were accompanied by faculæ they found that 584 had these faculæ to the left, 45 only had them on the right hand, and the 508 remaining had faculæ at both sides in the direction of the rotatory motion.

M. Faye seizes upon the preceding observations as confirmatory of his theory. However that may be they prove the existence of an evident connexion between the phenomena observed and the rotation of the photosphere. If, as the English astronomers assert, there can be no doubt that the faculæ are situated above the general surface of the photosphere, the retardation of these brilliant portions of the disc is easily explained by the combined action of the motion which has raised them to this higher level and that of rotation.

Such is, in a few words, the new theory of the Sun. It accounts for a certain number of the general phenomena without being able to explain the details, for instance, the granulations known as 'willow-leaves,' or 'ricé-grains;' moreover, it is subject to serious objections.

In the first place, it is difficult to realise the idea of so considerable a mass of gas, preserving its regu-

lar form, especially when this gas is supposed to be at such an excessively high temperature. Still, it is true that mathematical analysis applied to the solution of the figure of celestial bodies whose integrant molecules are subject to the law of attraction, and which turn with uniform motion around an axis, arrives at the solution quite independently of the physical state of the body, or rather by supposing that it was originally fluid, that is, liquid or gaseous. As to the density of the Sun, its specific gravity, which we have seen to be equal to the one-fourth of the mean density of the Earth, and consequently surpasses by more than one-third the specific gravity of water, it is not incompatible with the notion of the Sun being a gaseous body. Experiments made many years ago by Cagniard de Latour prove that the density of a gaseous body may become very considerable when this body is submitted to great pressure, at a temperature which surpasses considerably the point of liquefaction of the substance experimented on.

A more serious objection is that which Professor Kirchhoff makes to M. Faye's theory.

'M. Faye,' says he, 'imagines that the nucleus which is surrounded by the photosphere is as hot as—hotter even than—the photosphere, and yet dark. He imagines this nucleus to be gaseous, and having in view the slight radiating power of gases, he imagines these two properties to be compatible with each other in the

nucleus of the Sun. Now from the connexion which exists between the radiating and absorbing power of bodies, it results most certainly that, even should the light emitted by the nucleus of the Sun be invisible to our eye, this nucleus, whatever be its nature, must in this case be perfectly transparent, so that we should see through an opening in that hemisphere of the photosphere turned towards us (through the entire mass of the solar nucleus), the inner side of the other half of the photosphere, and we should experience the same luminous sensation as if there were no opening.'—('Comptes Rendus,' 1867, I. p. 400.)

It is difficult to answer this objection; M. Faye thinks, however, that to a medium like the globe of the Sun, which is about a million of miles in thickness, we can scarcely apply the physical law which establishes that the radiating power of a gaseous mass is necessarily complementary to its power of transmission.*

* [For our part we cannot see how distance or dimensions can in any way affect the operation of a physical law. The foregoing exposition of M. Faye's theory of the Sun will give our readers some idea of the very slight knowledge we possess of its physical constitution, and also how easy it is for men of the soundest intellect, and possessed of the most profound knowledge of astronomy, to wander towards the regions of the absurd, when they quit the path of observation for that of conjecture.—P.]

§ 6. The Prominences of the Sun seen during a Total Eclipse.

Prominences, Corona and Aureola.—Chemical nature of the Prominences; Spectral Analysis of their Light; Observation of the Eclipse of the 18th August, 1868, by Janssen, Rayet, and Tennant.—Consequences deduced from these Observations.—Continuous Stratum of Hydrogen enveloping the Photosphere.—Connexion of the Prominences with the Spots and the Faculæ.

Total eclipses of the Sun are due, as every one is aware, to the temporary interposition of the dark disc of the new Moon between the Sun and the observer. Our satellite in this case acts as an opaque screen, which for the space of a few minutes arrests the rays of solar light, and prevents them not only from reaching the surface of the ground, but also all that region of the Earth's atmosphere which is plunged into the cone of shade caused by the Moon.

This highly interesting phenomenon supplied for a long time only data connected with the greater or less degree of obscurity experienced in those regions of the Earth over which the lunar shade travelled. However, since the commencement of the last century observers have remarked that during the short phase of total darkness a luminous corona makes its appearance, being generally of silver whiteness, but sometimes coloured, and surrounds most completely the dark

limb. Beyond this corona, the apparent breadth of which varies from one-fifth to one-twelfth of the diameter of the Moon, the light decreases gradually, striped sometimes by diverging rays, which give to the phenomenon somewhat of the aspect of the aureola or glory which painters usually place around the heads of saints. In the more recent total eclipses also certain luminous jets of various shapes, distributed irregularly around the periphery of the lunar disc, have been observed. Some examples of these luminous phenomena may be seen in the figures 51 to 57.

At the present day it is generally admitted that the decreasing brilliancy, the rays and the tufts of light, must be classed as phenomena of diffraction, owing probably to the passage of the Sun's rays along the denticulated edge of the Moon.* But as regards the narrow and regular corona which surrounds the disc during total obscurity, it has been asked whether it does not indicate the existence of a solar atmosphere. As for the old hypothesis which admitted that this corona was the atmosphere of the Moon lighted up by the rays of the Sun, it has been proved to be unfounded.

Arago leaned towards the opinion which considers the corona to be owing to an atmosphere surrounding the Sun, and extending to a great distance. In

* [That is to an optical effect, such as we experience when we look at the flame of a candle with the eyes nearly closed, so that the rays pass through the eyelashes.—P.]

order to verify this supposition, he endeavoured to ascertain whether or no the light in question was polarised, but neither his own observations nor those of other astronomers led to any decisive conclusions on this point. In 1858 M. Liais found that the light of the corona is really polarised, and at once concluded that the Sun has an atmosphere extending far beyond the photosphere.

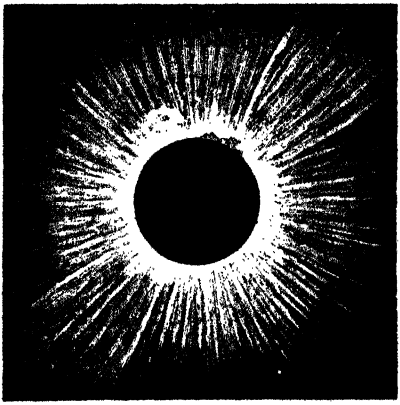


Fig. 51.—Total Eclipse of the Sun, 8th July, 1842. Prominences and Aureola.

There are, however, other reasons which induce us to believe in the existence of such an atmosphere. In the photographs of the Sun, obtained at the Kew Observatory, a very notable difference of intensity is observed between the borders and the centre of the solar disc, we have already referred to this difference, which is easily explained by admitting that the rays emanating from the photosphere travel through an absorbing atmosphere; for from the edges of the disc the distance travelled by the rays of light to reach us is very much greater than from the centre. 'It is worthy of remark that the temperature of this atmosphere must be

lower than that of the photosphere, otherwise the absorption which it occasions would be counterbalanced by its own radiation.' (De la Rue, Stewart, and Loewy, 'Researches on Solar Physics.')

Let us now refer to the phenomenon observed since the year 1842 in most of the total eclipses of the Sun, phenomena which are of the highest importance in the investigation of its physical nature.

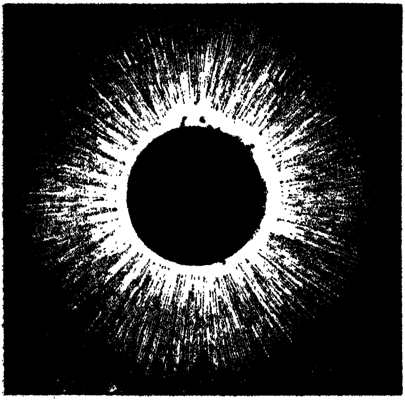


Fig. 52.—Prominences seen of the 28th July, 1851, by Dawes.

In the figures 51, 52, 53, and 54, may be seen irregularly situated around the dark limb of the Moon a certain number of appendages, some in form like mountains, like peaks, or pyramids; others rising like columns sometimes vertical, sometimes bent or inclined, and occasionally detached entirely from the edge of the disc, and floating above it. It is to these luminous appendages, of a reddish or rosy tint, that the appellation of *prominences* (or *red protuberances, red clouds, red flames,* &c.) has been given. Now what are these singular appearances? Are they real objects or optical il-

lusions? Do they belong to the Moon or to the Sun?

All these questions have been asked and responded to in various ways, but now-a-days there exists no doubt as to their being real objects, and it is equally certain that they belong to the Sun, or at least to those regions of space which immediately envelope the the Sun's photosphere. We have many decisive proofs of this.

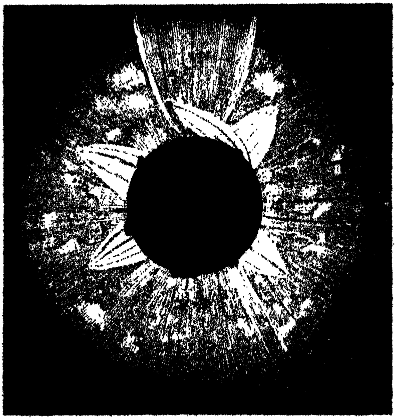


Fig. 53.—Total Eclipse of the Sun on the 7th Sept. 1858, according to M. Liais; tufts of Light and Prominences.

On examining the remarkable photographs obtained in July 1860, by Warren de la Rue (fig. 55), it was almost possible then to give a decisive answer. Two of these photographs represent the phenomenon as seen, after the commencement of total obscurity, and a little before the end of the same phase; and it is observed that the dark disc of the Moon which first masked the prominences on the side of first contact, allowing those on the opposite side to be seen, produced a contrary effect by its motion across the solar disc, so that near the

end of totality the prominences first seen were masked in their turn, whilst those opposite became visible. These appearances would be impossible if the appendages in question belonged to the Moon, whilst they are easily explained if we suppose that they cover the surface of the Sun.

But very satisfactory proofs that the prominences are realities and not optical illusions, and that they belong to the solar globe, were furnished by the observations of the magnificent total eclipse observed in India on the 18th August, 1868, and spectral analysis, applied in an ingenious manner by Messrs. Janssen and Lockyer, has also contributed to this result. The study of the solar prominences, thanks to these distinguished astronomers, is no longer limited to the short duration of a solar eclipse; they may be observed at any period of the year, and this fact alone proves evidently that they belong entirely to the Sun, and that the interposition of

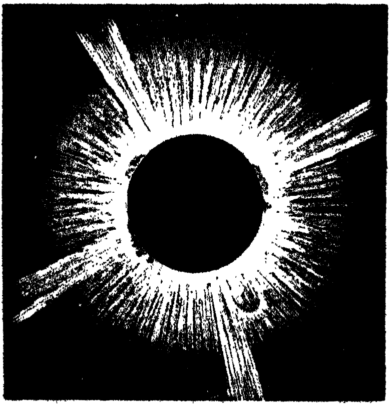
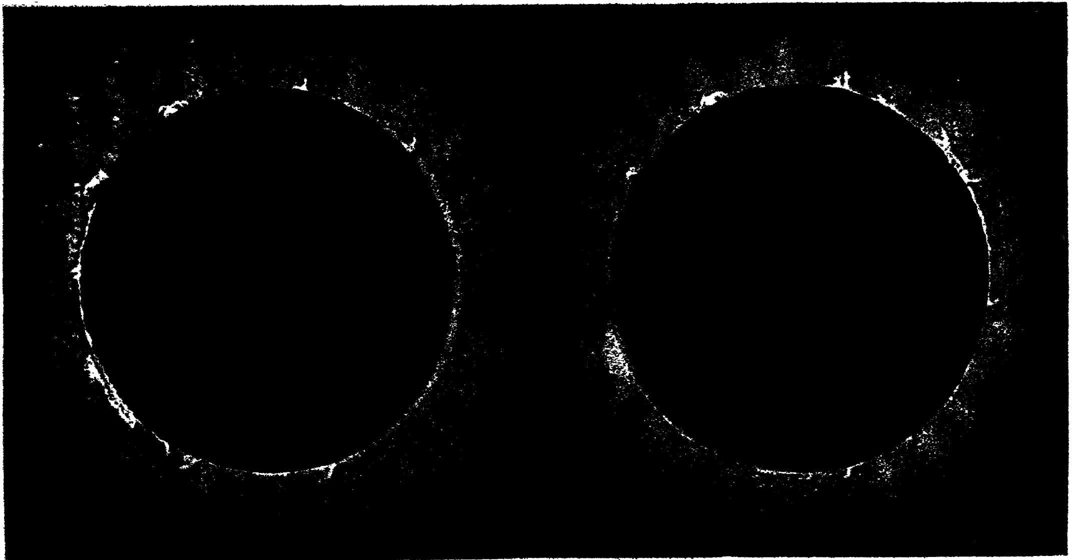


Fig. 54.—Total Eclipse of the 18th July, 1860. Aureola, Corona, and Prominences, from a Drawing



Commencement of Totality. End of Totality.

Fig. 55.—Solar Prominences seen during the Total Eclipse of the 18th July, 1860, from drawings by Warren de la Rue.

the lunar globe has nothing to do with their production.

Let us now notice a few details of the more recent and important observations.

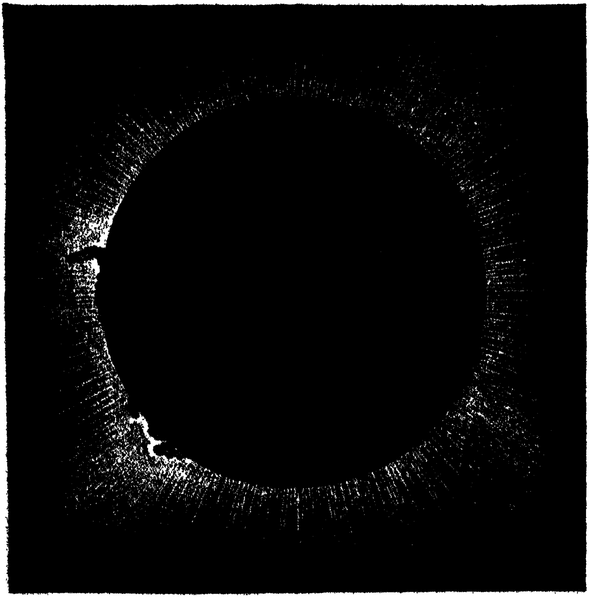


Fig. 56.—Total Eclipse of the 18th August, 1868. Gaseous Prominences seen the commencement of Totality, from Drawings made at Guntoor, Ind (Major Tennant.)

By a glance at fig. 56 will be seen two groups of prominences, just as they showed themselves to the observers of the eclipse, from Aden to Malacca, at the commencement of totality (total obscuration). 'One

of them,' says M. Janssen, 'that on the left, has a height of at least 3′; it resembles the flame of a forge-fire, rising violently from the interstices of the combustible whence it is forced by the violence of the blast.

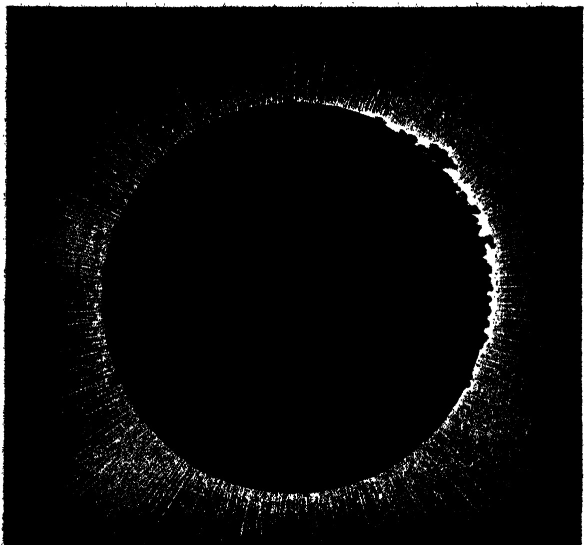


Fig. 57.—Total Eclipse of the 18th August, 1868. Gaseous Prominences seen at the end of Totality. (Major Tennant).

The prominences on the right (western edge), appear like a mass of snow-capped mountains, the bases of which rest on the limb of the Moon, and lighted up by the rays of a setting Sun.'

When the movement of the solar disc had masked from view this first group of prominences, and just as the totality was about terminating, some others showed themselves on the opposite edge of the Sun: they are those which are represented on fig. 57, and form around the solar globe a denticulated and continuous series of projections of very curious appearance. 'In the large telescope,' says M. Stéphan, another observer of this eclipse, 'the prominences were seen very distinctly; their colour was that of red coral, slightly tinted with violet. They all appeared to be adherent by their bases, and none of them floated, detached at a certain distance from the Moon, as was observed in 1851 and 1860.'

Besides the existence of prominences and their evident connexion with the solar disc—data which had been established already by observing previous eclipses—that of an exceedingly brilliant diaphanous layer or stratum was remarked, showing itself immediately after the second contact, and again a few seconds after the third contact. In 1860, shortly after the commencement of total obscurity, and a little before its termination, this same transparent layer had been observed, and it must not be confounded with the corona; whilst the light of the latter is white, the layer mentioned here appeared of a purple red colour to Le Verrier and Ismail, who observed the eclipse of 1860. It had various heights of 8, 10, and 15 seconds from the edge of the Sun.

We now arrive at the most important of the observations made on the 18th August, 1868, those which have chiefly occupied the attention of astronomers, namely, the investigation, by means of spectral analysis, of the light emitted by the prominences, calculated to supply data for determining their physical nature and their chemical composition.

All the observers of this eclipse who used the spectroscope, M. Rayet, Lieut. Herschel, Major Tennant, and M. Janssen, found that the spectrum given by the prominences was formed of a certain number of *bright* lines. Lieut. Herschel noted three such lines, a red one, an orange one, and a blue one. Major Tennant counted five situated near the ordinary lines of the solar spectrum (Fraunhofer's lines), C D E F G. M. Rayet saw no less than nine, among which he noticed that five were much more intense than the others. M. Janssen remarked five or six very brilliant lines, red, yellow, green, blue, and violet, and he immediately recognised that the red and the blue lines coincided with the dark lines C and F of the solar spectrum,—lines which are characteristic of hydrogen gas.

This had no sooner occurred than M. Janssen thought these rays might be visible without an eclipse, and sought to observe them the next day. On the 19th August, in the morning, in fact, he saw them again, by directing the spectroscope to the edges of

the Sun. But Mr. Lockyer, in England, had already, some two years before,* intimated the possibility of making such an observation, and on the 20th October, 1867, when he learnt what rays had been given by the prominences during the eclipse of the 18th August, he succeeded, at London, in seeing several of them. In the meantime M. Janssen and several others, to whom this new fact was made known, followed up these observations, and although there still remain certain doubtful points, the following facts may be considered tolerably certain.

1. The prominences (or protuberances) belong decidedly to the Sun. Of this, as we have amply shown, there cannot exist the slightest doubt.

2. The prominences are of a gaseous nature; that is, they are composed of an incandescent gas, principally hydrogen gas, but they contain, doubtless, other substances, perhaps substances that are unknown on the surface of our Earth, at least such would appear to be proved by the existence of a brilliant line in their spectrum, near to the yellow line of sodium, but not coinciding with the latter, and moreover, most curious to relate, it does not coincide with any dark ray of the solar spectrum.

3. The matter which forms the prominences is of very great extent, whether it spreads over the entire

* [In an article contributed to 'Macmillan's Magazine.'—P.]

photosphere or not; it forms a continuous layer, the thickness of which is estimated by Mr. Lockyer at some 5000 miles on an average, and the prominences appear to be only portions of this layer projected to a certain distance from it, sometimes detached from it, and floating above it. The great prominence represented in fig. 56 measured upwards of 100,000 miles in vertical height above the photosphere.

4. These stupendous accumulations of incandescent gas undergo, in very short intervals of time, very great changes in their form and size, which indicates that the layer of gaseous matter of which they form part is in a state of constant agitation, the cause of which is unknown; perhaps it is the same that gives rise to the spots and faculæ.*

It now remains to clear up certain doubtful points, including many questions which both ancient and

* [Quite recently Mr. William Huggins has succeeded in seeing a solar prominence so as to distinguish its form. A spectroscope was used; a narrow slit was inserted after the train of prisms contained in the instrument, and before the object-glass of the little telescope. This slit limited the light entering the telescope to that of the refrangibility of the part of the spectrum immediately about the bright line coincident with C. The slit of the spectroscope was then widened sufficiently to admit the form of the prominence to be seen, but the spectrum then became so impure that the prominence could not be distinguished. The idea then occurred to the author of this observation to absorb a great part of the light of the refrangibilities removed far from that of C by means of a piece of deep-

modern observations have raised, but left unanswered.

For instance, does there exist a physical connexion between the spots—the black nuclei and penumbra—and the prominences, as the recent observations of Professor Secchi would tend to prove? Before the last total eclipse of the Sun this was denied; it was remarked that the prominences were seen in every degree of latitude, whilst the spots do not extend beyond a certain limited zone. However, it was noticed during the eclipse of the 18th August, 1868, that faculæ existed on the borders of the Sun's disc close to two groups of prominences. Again, on the 24th and 27th February, 1869, Padre Secchi saw two magnificent prominences shining at a point where two very brilliant faculæ existed near the edge of the disc. Are not these brilliant spots, called faculæ, produced by the accumulation of the rose-coloured matter

coloured ruby glass, when the prominences became distinctly visible. In the 'Scientific Review,' for 1st June, 1869, it is stated that M. L. Hugo has invented an instrument called a *pyrhelioscope*, which permits an observer to see the whole of the solar prominences at once. 'It is a kind of spectroscope endowed with an angular rotatory motion; the angle of the cone described is equal to the apparent diameter of the Sun. The rotation is rapid enough to permit the persistence of the successive visual impressions on the retina, so that the succession of spectroscopic images forms a circular halo round the disc of the Sun, which appears dark as in a total eclipse, and surrounded by the prominences in their true positions.'—P.]

pushed away by the eruption which gives birth to the spots?

Now, is the incandescent atmosphere, diffused with various thickness all over the photosphere, the only one which exists around the Sun? Do the prominences rise into a vacuum or into an atmosphere which is perfectly transparent? It yet remains for us to ascertain what medium causes the reversal of the bright lines by the absorption of a certain number of the rays of light emitted by the photosphere. Is it the continuous rose-coloured stratum, much less thick than those parts of it which are uplifted in the form of prominences or clouds, but probably much more dense? The intensity of the light of the photosphere, the spectrum of which is considered to be continuous, can only be caused, according to the reigning ideas in science, by solid or liquid matter in an incandescent state. Hence the hypothesis of a solid or liquid nucleus, as proposed by Herr Kirchhoff, or of a gaseous nucleus surrounded by clouds of solid or liquid particles or of dust, as supposed by M. Faye. Now, the recent experiments of an English chemist, Dr. Frankland, lead us to believe that a continuous spectrum may be given by a mass of gaseous matter in a state of incandescence, if submitted to great pressure and at a very high temperature. Its light would be so much the more intense the greater the pressure and the higher the temperature. Now,

at the Sun's surface gravitation is so intense that the pressure exerted by an atmospheric stratum some thousands of miles thick must necessarily produce an enormous effect.*

All these questions suggest themselves since the recent and highly important discoveries, the results of which we have condensed into a very small space, were made; and it is very probable that the investigation of the physical and chemical constitution of the Sun will soon make rapid progress. But we must draw no hasty conclusions;† with our new methods of observation new facts are being rapidly accumulated. We must wait until they are more numerous and concilia-

* [Dr. Frankland's experiments, to which we have already referred in a previous note, have been published in the 'Philosophical Magazine,' vol. xxxvi. p. 309.—P.]

† For this reason we only mention cursorily an hypothesis on the constitution of the Sun, made known lately by Mr. W. Gilman, of New York, according to whom the nucleus is an incandescent solid or liquid, surrounded by the photosphere, and around this again by an atmosphere which is only visible during an eclipse, when it forms the corona. The spots would be due to masses of scoriæ which collect at the surface of the nucleus and determine a very intense electrical action. Hence holes or perforations in the photosphere, caused by the deflagration of gaseous masses and production of spots, whose centres appear black by contrast. This hypothesis, of which we can only give here a general idea, lies halfway between that of Wilson and that of Kirchhoff.

tory before we can discuss the consequences. At the moment at which we write the different theories which we have examined are being warmly discussed and submitted to a strict revision, which will, perhaps, allow only certain fragments of them to subsist hereafter.

CHAPTER VII.

MAINTENANCE OF SOLAR RADIATION.

§ 1. OF HEAT AT THE SURFACE OF THE SUN AND IN ITS INTERIOR MASS.

Temperature of the various Regions of the Solar Globe.—Calorific Radiation from the Centre and Borders of the Photosphere, from the Faculæ and the Spots.

THE force of the heat radiation of the Sun has been approximately measured, as we have already seen. But the data thus obtained give us no notion of a very important subject, namely, the intrinsic temperature which reigns at the surface of the immense sphere or in the depths of its substance. If this problem could be solved, it would teach us whether there is any analogy between this immensely powerful source of heat and those sources with which we are acquainted on the surface of the Earth, originating in electrical and chemical action.

Unfortunately, we are reduced to conjecture on this

head, because certain elements of the question are still wanting. We should know the emissive power of the Sun, and all we can do in the absence of this knowledge is to suppose it comprised within certain limits. That was the course taken by M. Pouillet, who arrived at the following conclusion:—Supposing the emissive (radiating) power of the Sun to be expressed by unity (= 1), its temperature is at least 1461° centigrade, which is about that at which iron melts; it would be 1761° C., if we suppose the radiating power of the Sun to be analogous to that of polished metals.

In M. Faye's hypothesis, which considers the entire mass of the Sun to be gaseous, the temperature of the internal strata is supposed to surpass very considerably that at which chemical action can manifest itself. But, in his opinion, whatever this temperature may be, the emissive power of the mass must be very weak, and its radiations entirely superficial, as each strata would possess a special power of absorption towards the rays emitted by the deeper strata. 'In fact,' says he, 'the temperature at the surface of the Sun is far below its internal temperature. M. Pouillet's measurement of the actual intensity of solar radiation has enabled Sir William Thomson to conclude that the heat emitted is only from 15 to 45 times higher than that which is developed in the fireplaces of our locomotives.'

The spectroscopic observations made during the total eclipse of the 18th August, 1868, and since then, have shown that there exists above the photosphere an immense stratum of hydrogen gas in an incandescent state, estimated by Mr. Lockyer to extend to a height of 5000 miles; above this stratum rise from time to time gaseous columns of like nature, which form the red prominences. If we apply to the combustion of these masses the data furnished by the combustion of hydrogen gas in the laboratory, we must conclude that the heat of the Sun — at least that of its external surface — cannot be less than 2500° C.

According to the observations of Padre Secchi, it would appear that the various regions of the Sun's surface have not all the same degree of temperature. Besides the differences noted between the borders and the centre, which is solely attributable to atmospheric absorption, there is another existing between the polar and the equatorial regions, the latter are said to be hotter than the others; moreover, the northern and southern hemispheres of the Sun would also appear to differ slightly in temperature. Herschel formerly supposed that one hemisphere radiated more light and heat than the other; but he meant the two hemispheres which are successively presented to the Earth during the Sun's rotation, not those separated by the Sun's equator.

The director of the Roman Observatory has also

compared the temperature of the spots with that of the more luminous parts of the photosphere, and with the faculæ; he finds that the spots are the coolest portions of the surface, but that there is no appreciable difference between the temperature of the faculæ and of the photosphere in general. M. Chacornac has also noted that the spots have a lower temperature than the other portions of the disc; but he states that the faculæ which follow a spot are at a higher temperature than the rest of the photosphere.

Let us not forget that, in all this we do not speak of the actual temperature, properly so called, of the various regions compared together, but of their relative powers of transmitting heat to us. To ascertain their actual temperature we must first know the radiating power of the various regions of the photosphere, of the spots, and faculæ, which we do not. It is, therefore, quite possible, as M. Faye's theory requires, that the inside, or nucleus, of a spot is really much hotter than the luminous portions of the photosphere: it would suffice, for this, that this inside was composed of a gaseous incandescent mass of little or no radiating capacity.

§ 2. Is the Sun getting colder? If not, How is the constancy of its Radiation to be explained?

Solar Radiation cannot result from ordinary Combustion.—Various conjectures on this subject; Heat developed by Rotation; by Falling of Meteors.—Helmholtz's Theory; origin of Solar Light and Heat.—Transformation of Gravitation by gradual Condensation of the substance of the Primitive Nebula.

If the mind is bewildered in calculating the myriads of myriads of centuries which must have elapsed since the solar nebula was condensed into an incandescent mass, and since the formation of our Earth to the present time; if the few hundred thousand years which probably measure the existence of the human species upon the globe are only as a second of time in the life of the Sun, where shall we find an argument which may assure our posterity that the Sun — the common father of our planetary world — is subject to the law that governs all things which exist — that as it was born, developed, lived, and still lives, a time will come when all its powers having been gradually dissipated into space, it will pass from the state of a radiating star into that of a dark globe, and thus end its existence? Will it ever be possible for mankind, by the aid of some peculiar phenomenon,

some hitherto unknown or unheeded manifestation, to measure a single phasis of this existence, a single minute of this life?

The Sun appears to us, it is true, as a primitive radiating source, finding in itself the energy of its own light and heat. But the time has fled since it was considered to be a *pure fire*, inexhaustible and imperishable, the time when belief in the incorruptibility of the heavens — *cœla incorrupta* — was cherished. At the present day we know that radiation of heat and light represents a real loss as regards the body whence this radiation emanates, and that if nothing supplies the place of this loss, if nothing maintains the combustion or the incandescence, a moment must come when such a source will be completely extinguished.

In the first place can we, arguing from the data we possess on solar radiation, assert how much its temperature is lowered in a year, in a century, in any given period? Pouillet considered this problem; and at the same time he showed that we cannot solve it. In order to do so, we must be acquainted with two elements of the Sun's physical constitution, namely, the conducting power of the substance of which its globe is formed, and its specific heat. On the supposition of a perfect conductibility, and admitting that the specific heat of the Sun is 133 times greater than that of water, Pouillet was led to the conclusion that

the temperature of the Sun would sink 1-100th of a degree (centigrade) per annum, or 1° C. in a century. In 10,000 years it would have cooled, then, to the extent of 100°.

Now, has the Sun cooled at all since the earliest historical periods? Nothing, as far as we know, permits us to reply affirmatively to this question when we look back through the records of the few thousand years embraced by history. It may be that, some day, the past history of our planet will throw some light upon this problem; but it must not be forgotten that a demonstrated change of climate or of the mean temperature of the Earth, may find its explanation in certain terrestrial phenomena as well as in a variation of the intensity of solar radiation: the problem will always be a very complicated one to solve.

We are authorised to state, however, that for some thousand years past no appreciable diminution has occurred in solar radiation; hence, we must conclude either that the cooling process is much slower than in Pouillet's supposition, or, that the Sun's heat is constantly maintained by some means with which we are totally unacquainted. We have just seen that if the loss of heat is not supplied the Sun would cool 100° C. in a century; and this is supposing it to possess an enormous specific heat: if the latter were no greater than that of water, it would not be 100° but 14,000° that the Sun would cool in a century: which is as much

as to say that in this short space of time it would be entirely extinguished.

According to Professor Tyndall, no kind of combustion, no chemical affinity, with which we are acquainted could maintain solar radiation. The chemical agency of the substances of which we have any knowledge is too weak, and they would be too soon dissipated into space. If the Sun was a mass of coal and was supplied with enough oxygen gas to make it burn with its actual degree of intensity, it would be entirely consumed in about 5000 years.

The question remains then as it was, and we are naturally led to inquire how the constancy of solar light and heat is maintained, or what keeps up this prodigious intensity; for the mass of the Sun, however enormous, does not suffice to explain its permanent state of incandescence during a long series of centuries, if we consider it as a combustible body feeding upon itself.

Several hypotheses have been proposed and discussed on this head; we will take a rapid glance at them.

It has been said that the Sun turning upon its axis in 25 days, its surface must rub against the medium in which it turns. Hence its light and its heat, developed by transformation of this friction. But what can this matter be which presses thus like a railway-break against the periphery of the solar

globe? Is it that which physicists call 'Ether?' Such a supposition is evidently inadmissible; for its action would be felt by the various planets with much greater intensity, since their rotation, and especially their translatory motion in the orbit is much more rapid. Moreover it has been calculated that if the entire force of the Sun's rotation were converted into heat, it would only supply the actual amount of radiation for about a couple of centuries. This hypothesis may, therefore, be dismissed at once, as insufficient in itself, and, moreover, as being in contradiction with observation; for, during the last two centuries no diminution in the velocity of the Sun's rotation has been observed.

A second conjecture, or opinion, defended vigorously by Mayer, Waterston, and William Thomson, endeavours to explain the constancy of the Sun's light and heat by the fall of meteors or aerolites upon its surface.*

Around the Sun a multitude of bodies gravitate. Some, like the planets actually known to us, describe orbits whose longer axes are nearly invariable, and have been so, since the earliest historic periods. We

* See Mayer, 'Dynamik des Himmels;' Waterston, 'Report of Brit. Assoc. 1853;' W. Thomson, 'Transactions of the Royal Society of Edinburgh, 1854;' also T. L. Phipson, 'Meteors, Aerolites, and Falling Stars,' pp. 173 and 212. London, 1867, where this opinion is objected to.

know, even, that the theory explaining the perturbations which they exert one upon the other, assures us this invariability must be maintained for a long series of centuries; and this proves to us that the medium in which they move can offer scarcely any resistance to their motion. Besides the planets, the number of which is now 116, there exist a multitude of comets, probably millions, that describe very much more elongated orbits, and whose masses, comparatively small, render them liable to experience considerable resistance. The comet of Encke, for instance, approaches visibly to the Sun as the length of its period diminishes, and if this acceleration continues, the day will come when, after describing a spiral course round the central orb, the comet will precipitate itself on to the surface. Other smaller bodies circulate in much greater numbers round the solar globe. We allude to those called meteors or falling stars, which, at certain periods of the year, appear in swarms, and grazing the atmosphere of the Earth with planetary velocity, take fire, and sometimes fall to the surface of our globe. These swarms, the streams of which have been recently assimilated to, or perhaps identified with, cometary masses,* appear, some of them, to describe parabolic

* The ingenious theory of the Italian astronomer, Signor Schiaparelli, Director of the Observatory of Milan, explains the periodicity of shooting stars by the passage of the Earth through long streams of small bodies which solar attraction

curves, which indicate that they visit the regions of our Sun for the first time, whilst others move in more

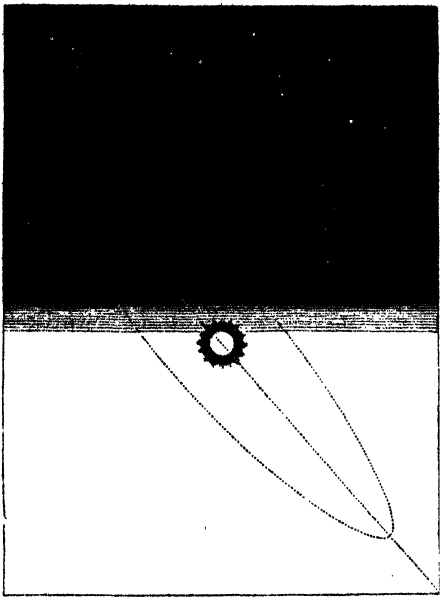


Fig. 58.—Zodiacal Light. Direction of its Axis.

or less elongated ellipses. Gradually these masses, individually very small, undergo the same resistance

causes to describe parabolic orbits, analogous to cometary orbits. The comets themselves, in his opinion, are nebulosities of the same kind; some of which end by circulating periodically around the Sun, and remain attached to our solar world. We shall say a few words on this new and important theory further on.

that accelerates the comet of Encke, approach the Sun, and by their vast numbers increase the density and resistance of the medium in which they move. Such would be the cause of that peculiar luminosity known as the *zodiacal light*, the plane of which coincides nearly with that of the ecliptic or the solar equator, and which spreads itself in the form of a lenticular zone to a distance from the Sun equal at least to the mean distance of the Earth.

All these meteors, or rather, these streams of meteoric matter, circulate round the focus whose light they reflect; but at the same time, by their collisions, and by the resistance they oppose to each other's movements, their translatory velocity is accelerated, so that we may conceive a constant stream of them rushing incessantly to the Sun, a constant shower of meteors, in fact, upon its surface.

Supposing such a thing to occur in reality, does it account for the constancy of the solar light and heat? On the one hand, it supposes an increase of substance, an increase of combustible matter; and on the other (and this was considered the strong point of the theory), the fall of each meteor occasions at the Sun's surface, by the simple transformation of its accelerated velocity into heat, a degree of temperature very considerably greater than that due to the combustion of its substance.

Dr. Tyndall says it is easy to calculate the maxi-

mum and minimum velocity communicated by the Sun's attraction to an asteroid circulating round it; the maximum occurs when the asteroid approaches the Sun in a straight line, coming from an infinite distance, for then the entire force of attraction acts upon it without any loss; the minimum is the velocity which would be merely capable of causing to revolve round the Sun a body in close proximity to its surface. The final velocity of the first body would be 392 miles per second, that of the second 271 miles. The asteroid striking the Sun with the first of these velocities would develope more than 9000 times the heat produced by the combustion of an equal mass of coal.*

It is, therefore, completely unnecessary to imagine that the substances supposed to fall on the Sun must be combustible; this property would add nothing, or

* According to Sir W. Thomson, the following table expresses the heat that would be developed at the Sun's surface by the fall thereon of the eight principal planets, supposing them to fall in a straight line; the quantity of heat is expressed here by the period during which they would maintain the present degree of solar radiation:—

	Years.	Days.		Years.
Mercury ...	6	214	Jupiter ...	32,240
Venus ...	83	227	Saturn ...	9,650
The Earth...	94	303	Uranus ...	1,610
Mars ...	12	252	Neptune...	1,890

So that all these planets together, in falling upon the Sun in a straight line, would only maintain its heat for a period of 45,588 years, a mere nothing!

scarcely anything, to the enormous temperature developed by their collision—by the mechanical shock alone.

We have then here a mode of heat-production which would suffice to restore to the Sun that which it loses by radiation, and to maintain at its surface a temperature which would surpass that of any earthly combination. The properties of the solar rays and their power of penetration into bodies authorise us to look upon the temperature of the source as something enormous; and in the falls of meteors, says Tyndall, we have the means of producing this excessive temperature. It may be objected, that such showers of solid matter must increase the volume of the Sun; and this is true, but the quantity of matter necessary to produce the actual radiation, even if it should have accumulated for the last four thousand years, would escape observation aided by our most powerful instruments. If the Earth fell into the Sun, the increase of volume would still be inappreciable; nevertheless, the heat produced by the shock would supply that radiated by the Sun in a century. The fall of the Moon on to the Sun's surface would supply the Sun's loss of heat for one or two years, and its volume is only the 1-64,000,000th of that of the Sun.*

* Moreover, if the Sun, by constantly attracting meteors to its surface, increased in volume and mass, still its incessant radiation, as constantly lowering its temperature, would occasion

Such is the hypothesis known as the *meteoric theory of solar heat*, a very ingenious theory, and one which is physically very truthful in appearance, as it is based upon a fact and a principle which are at the present day acknowledged in science, namely, the transformation of mechanical motion into heat. Nevertheless, one of the three authors of this theory, Sir W. Thomson, has abandoned it, as being incompatible with a well-ascertained fact—the impossibility of the existence of a resisting medium in the immediate neighbourhood of the Sun. In fact, several comets, those of 1680 and 1843, for instance, have passed so near to the Sun's surface when at their perihelion, that they would have experienced very considerable perturbations in their motion if any dense medium, such as that supposed by the meteoric theory, existed in reality. But such a medium is not essential to the theory, since the same cause which accelerates the motion of Encke's comet—and this acceleration, as well as that of Faye's comet, is a well-observed phenomenon—is capable, in the long run, of precipitating meteoric streams on to the Sun's surface.

a contraction of volume, so that whilst they supplied the loss of light and heat, the meteoric bodies would compensate for its contracted volume. Its mass and its density alone would increase continuously. [In my work on 'Meteors,' &c., p. 212, I have alluded to the fact that such an augmentation of mass would necessitate an acceleration in planetary revolution.—P.]

However that may be, if the meteoric theory of the constancy of solar light and heat were admitted to be true, two consequences might be deduced from it which, perhaps, deserve to be mentioned.

The first is suggested to us by Professor Schiaparelli's theory of the periodicity of meteor-streams. In his opinion the origin of this periodicity is *without* the solar system, like that of a certain number of comets: they are nebulous masses which the attractive force of the Sun draws into its sphere of activity, and which come *from the depths of interstellar space*, describing a parabolic curve around the focus of our world, and after having passed in long streams for many successive years, returning into distant space whence they came. Some of them thus escape, perhaps, from the Sun's attraction; others are deviated from their primitive orbit by the action of the planets they approach, which transforms their parabolic course into an elliptic one, and thus enriches the solar system. If this be the case, and if we remember that the Sun itself travels in an immense orbit, the focus of which is unknown, the vast incandescent solar globe may be represented as ravaging space to contribute to its own powerful substance, like the great fish that traverse and depopulate the waters of the ocean. Hence the Sun would not be reduced to feed upon the comparatively small amount of meteoric matter that exists at any given moment in its immediate neighbourhood, and it is easy to conceive

that as fast as it devours these legions of meteors other provisions of them are made for the future, and so on *ad infinitum.*

Another remark that might be discussed is this:—

Would not the fall of meteoric streams on to the surface of the Sun account for the phenomena of sun-spots? Up to the present time, as far as we know, these spots have been explained by appealing to the innermost strata of the central orb; at least the only external origin that has been proposed to explain them is the influence of the planets.

We have exposed the various hypotheses brought forward on this subject; here we must add one more:—Suppose a mass of meteors precipitated on to the solar globe with the considerable velocity which animates each of these corpuscles, is it not probable that it would produce a hole in the luminous photosphere, which excavation would be in proportion to the breadth of the stream? If the shower only lasted a short time the spot would be of short duration, but if the stream were a very long one, the excavation or spot would last much longer. The configuration of the spots, the nuclei and other phenomena, would be explained in this hypothesis, as well as in any of those which admit that the spots are excavations in the photosphere. Moreover, the limited zones in which sun-spots appear would be connected with the inclinations of the original orbits described by these swarms of meteors

before their precipitation on to the surface of the Sun.*

To conclude what we have to say of the constancy of solar radiation, it remains for us to examine a theory which explains its maintenance by the transformation into heat of gravitation—the force which formerly condensed into a single nucleus the molecules of the original nebula. At first these molecules were relatively at considerable distances from each other (but endowed with gravity like all matter), and formed a confused or chaotic mass. Under the influence of gravitation they have been gradually condensed into a nucleus, which has become the centre of attraction for the whole mass. The molecules of the nebulosity precipitating themselves one upon another, according to Professor Balfour Stewart, produced heat, 'just as a stone produces heat when it is thrown violently from the top of a precipice, when heat is the final form taken by its potential energy.' This theory, so far, does not differ essen-

* [As the translator of this little work has not long since published a volume on the phenomena presented by meteors, aerolites, and falling stars, he may, perhaps, be allowed to state here his opinion, that this meteoric theory of solar light and heat, and the consequences deduced therefrom, are not likely to remain long in science. Already its most ardent promoter, Sir William Thomson, has abandoned it, and though the theory of Professor Schiaparelli, which points out certain periodic analogies between comets and shooting-stars, is highly ingenious, it is yet little more than a matter of pure speculation.—P.]

tially from the former. It is still the transformation of mechanical force into heat which is put forward to explain the heat of the Sun; only it does not assume a fall of extraneous bodies to explain solar radiation, it appeals to the molecules which originally formed the radiating body itself. This attraction and precipitation of molecules one upon the other may be considered from another point of view—that of the condensation of the mass of the Sun. Now we know that condensation is always accompanied by a production of heat. It has been calculated that a diminution of 1-1000th of the Sun's diameter would produce heat enough to suffice for its entire radiation during 21,000 years.

Professor Helmholtz who made this calculation, author of the theory we now discuss, has, moreover, estimated that 'the mechanical force equivalent to the mutual gravitation of the molecules of the nebula would have been originally equal to 454 times the quantity of mechanical force actually at disposal in our system. 453-454ths of the force caused by the tendency to gravitate will, therefore, have been already expended in heat.' But if that which remains were entirely converted into heat, it would be sufficient to raise to 28 millions of degrees centigrade the temperature of a mass of water equal to the united masses of the Sun and the planets; this quantity of heat is 3500 times greater than that which would be furnished

by the combustion of the entire solar system, supposing it to be composed of the best Newcastle coal.

We need have no anxiety then, on this point, nor the generations which will follow ours for many thousands of centuries to come. Our provision of light and heat is assured for a future, the long duration of which we are quite unable to estimate. Humanity, as compared with the age of the Earth, is yet in its most tender infancy. 'The period of time during which the Earth has nourished organised beings,' says Professor Helmholtz, 'is still very short when compared to the period during which it was a mass of molten rock. Bischof's experiments on basalt appear to prove, that to cool down from 1000° to 200° centigrade our Earth must have taken 350 million years. As for the length of time that has been required by the original nebula to condense itself into the form of our planetary system, it entirely defies our imagination and all conjectures.' Whatever, then, may be the extent of the fraction of this time which our world will enjoy, one thing is certain, namely, that it must be counted by millions of years. The end of the world by the cooling and extinction of the Sun is far enough from us!

§ III. Is the Sun a Variable Star?

What would become of the Earth and Planets if the Sun were periodically extinguished? Variable Stars; new Stars; temporary Stars; Stars which have disappeared.—Combustion of Hydrogen at the surface of the new Star in the Northern Crown.—Hypothesis of an increased Radiation from the Sun; of the complete Envelopment of the Solar Sphere by Spots.—Byron's Poem 'Darkness.'

The stars, as we said above, are suns, more or less similar to our Sun in the chemical composition of their photospheres, and having, at least, one important property in common with our Sun, namely, that of shining by light of their own, not by light which is borrowed from some other source, not by reflected light like that of the planets.

Now, among the infinite number of stars dispersed on the celestial vault, there exist some whose brilliancy is subject to variation, being sometimes fainter than before, and at others notably increased. Some of these show no periodicity in this variation of their luminous intensity, or, at least, such has never yet been established by observation; others are remarkable for their sudden appearance, they soon shine with the brilliancy of stars of the first magnitude, then decrease gradually in brightness, and disappear for centuries together, without leaving the least trace of their presence. In

certain portions of the heavens stars, which before were invisible, have appeared and remained visible since; whilst others, formerly visible, have disappeared altogether. Astronomers have given to the stars which present these curious phenomena, the following appellations:—Variable stars; periodically variable stars; new stars; temporary stars; stars which have disappeared. Many an hypothesis has been imagined to explain the cause of these variations. It has been conjectured that the said stars have a rotatory motion, and present to us unequally bright hemispheres, or that they are more or less flattened, so that we see them alternately wide and narrow; some have supposed that they are subject to sudden conflagrations, or to complete extinction of their light; lastly, their variability has been attributed to eclipses, or to the interposition of some dark bodies between them and our solar system.

All these conjectures may have some truth in them; they are, nevertheless, conjectures, and nothing more. But recent observation speaks in favour of one of them. About two years ago there appeared in the constellation of the Northern Crown a star, which was first thought to be new, but was afterwards recognised as one of the 9th magnitude indicated on the Catalogue. It appeared for a certain period with an unusual degree of brightness, so much so, that it became visible to the naked eye, and shone equal to a star of

the 2nd magnitude, the Pearl, in the same constellation.

Now, this 'new' star had its light examined by spectral analysis, and Mr. William Huggins put forward, as a very probable opinion, that it had been suddenly enveloped by flames of burning hydrogen. Some enormous convulsion, the cause of which cannot be conjectured, may have evolved an enormous quantity of gas; 'a great portion of this gas was hydrogen, which burnt at the surface of the star by combining with some other element, and this terrible deflagration heated the solid matter of the photosphere and rendered its incandescence more intense. When the hydrogen was all burnt, the flame gradually ceased, the photosphere became less luminous, and the star returned to its former state.'

This fact [if we must admit it] throws much light on the variability of a certain number of stars, especially those called temporary stars, like that known as the Pilgrim, which, in 1572, shone suddenly with great brilliancy, then became extinguished and disappeared.

The question which concerns us is, whether our Sun is likely, some day, to undergo such a variation of intensity—can it become the seat of such terrible phenomena?

The most recent observations show us that masses of hydrogen gas, in combustion, rise from the photo-

sphere, and constitute the red prominences. If such is really the case, two opposite effects can naturally ensue. The cause which produces the gaseous evolution may gradually diminish in energy, so as to lessen either the light or the heat radiation; or this cause may augment and increase the power of the immense central fire.

What would be the consequences of such changes? If they were sudden, no doubt they would be extremely terrible; for a very slight increase of solar heat would raise the mean temperature of the whole Earth, of every climate, and would modify most essentially the conditions of existence for the organised beings which live upon the surface. Suppose, for instance, that tropical heat extended to the temperate zones, the culture of wheat would be an impossibility, and the principal aliment of civilised nations would be at once cut off. A few more degrees of heat, and many species of animals, even man himself, could no longer exist on the surface of the globe.

A change in the other direction would be no less dangerous, for then the temperature of the polar regions would spread over the temperate zones, forcing animals and plants, which now occupy vast regions, to confine themselves to the narrow zone of the equator. After all, if such convulsions ever did occur, it is not certain that life would become extinct. The conditions being changed, would probably give rise, gradually, to a new

flora and a new fauna; but previously to this new emission of life the beings now existing would meet with destruction and death.

It is by supposing that the brightness of our Sun is variable, that some philosophers have endeavoured to account for the glacial period; but geologists do not admit their explanation. The changes which have gradually occurred in the distribution of land and sea suffice, according to them, to account for the extremes of climate through which our globe has passed, and which have gradually made way for the modified climates of the present day.

We have seen that the number of sun-spots appears to increase and diminish periodically. May this fact be admitted as a proof that our Sun must be classed among the variable stars? In short, are the spots which darken the disc capable of causing sufficient diminution in the intensity of solar radiation to be noticed at the distance of the fixed stars? Such may be absolutely the case, but, nevertheless, the change must be very slight, since the effects of it have never yet been noticed with certainty at the surface of the Earth.

Now, what would result if the Sun's photosphere were covered over by numerous and extensive spots? If the latter are produced by the effects of a lower temperature at these points of the solar sphere, it is evident that the result would be a decrease in the

amount of heat and light radiated by the Sun to the planets and to the Earth. If it were completely covered with spots, the glorious central orb would become transformed into a dark globe, and would cease to animate with its beneficent rays the worlds which gravitate around it. Death, destruction, cessation of movement, would everywhere succeed to life and motion. But these are merely flights of the imagination, which the prolonged stability of our system does not justify in the least, and the phantoms of which poets alone are allowed to invoke. Lord Byron has, indeed, described the terrible drama of which our world would, perhaps, be the theatre, if the radiant focus which supplies life to us and to all the beings which people the Earth were to become suddenly extinguished. We quote these few lines of poetry for those of our readers who may like to read quietly, by their firesides, an account of such grand fantastic scenes, and feed their imagination on sublime horrors :—

'I had a dream, which was not all a dream,
The bright Sun was extinguished, and the stars
Did wander darkling in the eternal space,
Rayless and pathless, and the icy Earth
Swung blind and blackening in the moonless air.
Morn came and went—and came, and brought no day ;
And men forgot their passions in the dread
Of this their desolation ; and all hearts
Were chilled into a selfish prayer for light.
And they did live by watchfires ;—and the thrones,

The palaces of crowned kings, the huts,
The habitations of all things which dwell,
Were burnt for beacons; cities were consumed,
And men were gathered round their blazing homes,
To look once more into each other's face.
Happy were those who dwelt within the eye
Of the volcanoes, and their mountain-torch!
A fearful hope was all the world contained.
Forests were set on fire — but hour by hour
They fell and faded — and the crackling trunks
Extinguished with a crash — and all was black.
The brows of men by the despairing light
Wore an unearthly aspect, as by fits
The flashes fell upon them; some lay down,
And hid their eyes and wept; and some did rest
Their chins upon their clenched hands, and smiled;
And others hurried to and fro, and fed
Their funeral piles with fuel, and looked up
With mad disquietude on the dull sky,*
The pall of a past world; and then, again,
With curses, cast them down upon the dust,
And gnash'd their teeth and howl'd: the wild bird shriek'd,
And, terrified, did flutter on the ground,
And flap their useless wings; the wildest brutes
Came tame and tremulous; the vipers crawl'd
And twined themselves among the multitude,
Hissing, but stingless — they were slain for food:
And War, which for a moment was no more,
Did glut himself again! — A meal was bought
With blood, and each sate sullenly apart,
Gorging himself in gloom: no love was left;

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* If the Sun alone were extinguished we should still have the aspect of the starlit sky — a very poor consolation, however, for a population of famished and frozen people.

All earth was but one thought—and that was death,
Immediate and inglorious: and the pang
Of famine fed upon all entrails—men
Died, and their bones were tombless as their flesh.
The meagre by the meagre were devoured;
Even dogs assailed their masters, all, save one,
And he was faithful to a corse, and kept
The birds, and beasts, and famish'd men at bay,
Till hunger clung them, or the dropping dead
Lured their lank jaws; himself sought out no food,
But with a piteous and perpetual moan,
And a quick, desolate cry, licking the hand
Which answered not with a caress—he died.
The crowd was famished by degrees, but two
Of an enormous city did survive,
And they were enemies: they met beside
The dying embers of an altar-place,
Where had been heap'd a mass of holy things
For an unholy usage. They raked up,
And shiv'ring, scraped with their cold, skeleton hands
The feeble ashes, and their feeble breath
Blew for a little life, and made a flame—
Which was a mockery. Then they lifted up
Their eyes, as it grew lighter, and beheld
Each other's aspects—saw, and shriek'd, and died—
Ev'n of their mutual hideousness they died,
Unknowing who he was upon whose brow
Famine had written Fiend. The world was void,
The populous and the powerful was a lump,
Seasonless, herbless, treeless, manless, lifeless—
A lump of death—a chaos of hard clay.
The rivers, lakes, and oceans all stood still,
And nothing stirred within their silent depths;
Ships, sailorless, lay rotting on the sea,
And their masts fell down piecemeal; as they dropp'd

They slept on the abyss without a surge—
The waves were dead; the tides were in their grave;
The Moon, their mistress, had expired before;
The winds were wither'd in the stagnant air,
And the clouds perish'd! DARKNESS had no need
Of aid from them—She was the Universe.'

EPILOGUE.

IS THE SUN INHABITED?

Physical impossibility of the Existence of organised and living Beings on the Sun's surface.—The Romance of an Inhabited Sun.—Logical Conditions imposed upon the Hypotheses which deal with the Habitability of the Celestial Orbs.

AFTER all that we have said respecting the nature of the Sun, or, as astronomers call it, its physical constitution, the question placed at the head of this chapter is, perhaps, scarcely worthy of being submitted to careful examination. If we take into consideration the high scientific authority of some men who have answered it in the affirmative, we are bound to look into it; not so, however, if we argue upon the most recent observations, or if we confine ourselves to analogy, or to the known laws of physical phenomena, such as we are acquainted with them upon the Earth—such as

they must also manifest themselves upon and in the solar globe.*

It is true that the partisans of Wilson's theory—and the illustrious François Arago was one of them, but it is fifteen years ago—believed that the solar globe or nucleus was comparatively dark and cold, being separated and preserved from the radiating photosphere by a thick layer of cloud endowed with the property of absorbing both light and heat. But it is precisely this hypothesis of a dark, cold nucleus, which is no longer admissible.

The interposition of matter acting as a screen, either opaque or endowed with very weak absorbing power for light and heat—supposing its existence to be proved—would only settle one thing, namely, that the internal nucleus is not heated by radiation. But if the photosphere is really in contact with the cloudy layer of the penumbræ, it must transmit its heat by conduction; as it envelopes the solar globe entirely it must heat it at every point of its surface, and even if the conducting power were very slight, equilibrium of temperature would, in time, be established in the

* [This is just the point which writers, such as Flammarion and others, who have recently argued for the Sun's *habitability*, dispute. Are 'physical phenomena' the same in the Sun as upon the Earth? they ask; if not, it may be inhabited—perhaps *by angels!*—See Flammarion's recent work 'La Pluralité des Mondes habités.' Paris, 1864, 2nd ed.—P.]

whole mass, and this temperature cannot be lower than that of fusion. Gases are, it is true, very bad conductors of heat, but their conduction is not *nil*, and its effects being accumulated for centuries, it is easy to see that equilibrium of temperature between the photosphere and the nucleus must be established. We must not forget, moreover, that gaseous matter gets heated throughout its mass by *convection*, or transportation of the heated portions by circulation among the cooler portions; and unless we suppose it to be absolutely at rest, its heat must thus be propagated very rapidly. Now, the phenomena of the spots, their rapid transformations, the movements which these transformations must cause either in the different layers of the photosphere, or in the deeper regions of the solar globe, appear to us to place beyond doubt the constant mixing of the different layers by a continual interchange of heat.

It is, therefore, extremely probable that the entire globe of the Sun has a very high temperature throughout its mass—a temperature which surpasses the melting [or boiling] points of most of the elementary substances of which spectral analysis has revealed the existence in its atmosphere. At the same time it is evident that the various concentric layers, of which the solar globe may be supposed to be formed, exert one upon the other considerable pressure, since we find that, at the surface itself, the intensity of gravitation is

twenty-eight times as great as upon the Earth's surface; this pressure may hinder fusion to a certain extent, but not incandescence. But we believe that the hypothesis of a liquid incandescent—or even a gaseous—nucleus is the more probable.

However that may be, it is absolutely impossible to understand how any living beings, animals or vegetables, could live in such conditions. It is all very well to conjure up a fantastic romance as to the kind of people who live in the Sun, to imagine them dwelling in a kind of hothouse, and observing the sky through the openings produced by the spots; but it is pure imagination and not science.

True it is, that in considering a problem so incompletely under control, we might reserve our opinion. The physical constitution of the Sun is yet too slightly investigated to enable any one to make an authoritative statement on this subject; we can only rely upon probabilities, but in doing so we must remain within the bounds of well-authenticated facts: we must not, in order to favour any gratuitous hypothesis, imagine at will the existence of physical laws different from those which observation and experiment have revealed. But this is the position taken up by those who believe that the Sun may be inhabited.

At any rate there is one fact which they cannot get over, namely, the constancy of solar light and heat—the prodigious expenditure of light and heat which the

thin envelope or photosphere certainly cannot suffice to produce, unless its incandescent state is kept up by heat from the interior of the Sun's mass. Whether we adopt the meteoric theory, or the transformation of gravitation into heat, we cannot suppose the internal nucleus of the solar globe to be at a low temperature.

Some writers have certainly endeavoured to support the supposition of such a low temperature by appealing to known physical phenomena. They have compared the globe of the Sun surrounded by its photosphere, to the spheroidal globule produced in M. Boutigny's curious experiments, a globule of liquid which remains colder than ice in a medium heated to whiteness.* But it is very evident that the conditions are widely different: in one case the medium is a gaseous incandescent mass; in the other it is a solid metallic or porcelain vessel. The solar nucleus is supposed by them to be solid, whilst the globule in M. Boutigny's experiments is a liquid.

A distinguished French astronomer, M. Liais, supposes that the grey atmosphere, which explains the

* [When a drop of water falls upon a red-hot sheet of iron it takes what is called the *spheroidal state*, and floats about on a cushion of steam as a globule of water whose temperature is below boiling-point. There is no immediate contact between the globule and the heated surface. Vide Boutigny, 'Etudes sur les Corps à l'état sphéroidal,' 1 vol. 8vo. Paris, 1857. When liquid sulphurous acid is used instead of water, its temperature descends below zero.—P.]

penumbra in Wilson and Herschel's theory, is endowed with properties precisely the reverse of those we recognise in our own atmosphere: the latter absorbs the rays of luminous heat, and is not traversed by rays of dark heat, which accounts for the slight loss of heat from the ground by diurnal or nocturnal radiation; on the contrary, the internal atmosphere of the Sun would, in his opinion, be opposed to radiation from the photosphere, but would allow the internal dark heat to traverse it freely. Thus would be explained the existence of a low temperature at the surface of the solar globe. Now, not only is this property of the grey atmosphere a gratuitous hypothesis, but it only applies to heating by radiation; it would not prevent heat being propagated by conductibility or convection.

In short, it appears to us extremely difficult to consider the Sun as a globe inhabited by organised beings; we have no idea what sort of life could exist in a medium at so high a temperature. All physiologists agree that no terrestrial being can exist in a temperature scarcely higher than 100° C., and it is not of 100°, but of 1000° and 2000° of heat we must speak when alluding to the strata of the solar globe immediately beneath the photosphere. How can we conceive plants or animals living in a temperature capable of melting metals?

We are well aware that those who establish as a dogma the habitability of the celestial globes, who will,

at any risk, people both the largest and the smallest of them, comets and nebulæ, sun and planets, with living beings, have a very convenient method of solving the difficulty and criticising the data which science brings forward in opposition to their doctrine. It consists in imagining that matter in these distant regions possesses different properties to those which it reveals to us in this world—properties which are unknown to us.

As a general rule, it is very true that where life is possible different kinds of organisms correspond to different physical conditions. Upon the Earth itself it is so; there is, necessarily, harmony existing between the living being and the medium in which it lives. But even these conditions have their limits, as is proved by the palæontological history of our planet: in the earliest periods life was absent, it was developed gradually or progressively, whilst the atmosphere and the soil underwent physical modifications.

Unless we fall back, then, to the superstitious ravings of times gone by, and believe in the existence of certain imaginary animals capable of living in fire, we cannot do otherwise than consider the Sun as a globe upon or in which life is absolutely impossible.

Will it ever become a habitable globe? Such is very possible; but at that period our Earth and the other planets will probably be no longer the theatre of life.

Nevertheless, the functions of the Sun, as far as life is concerned, are as important as those of the Earth and other celestial bodies which revolve around it. It is the focus of those powerful vibrations which carry life and movement everywhere, the interruption of which would be the signal of destruction and death to every organism upon the surface of the celestial globes which compose our solar world.

THE END.

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